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**OPERATION MANUAL FOR THE MARK II MODEL OF THE
LASER ABSOLUTE GRAVIMETER**

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*George C. Marshall Space Flight Center
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TECHNICAL MEMORANDUM X-64560

OPERATION MANUAL FOR THE MARK II MODEL OF THE LASER ABSOLUTE GRAVIMETER

SUMMARY

An absolute gravimeter utilizing the principle of a Michelson Interferometer is currently undergoing development at NASA's Marshall Space Flight Center, Huntsville, Alabama. The current model, Mark II, is a second generation of the original Mark I Laser Absolute Gravimeter. Its description, operation, principles of operation, alignment, and maintenance are presented in this document.

The report documents the present de facto status of the present Mark II instrument. Amendments to the manual will be forthcoming when the work has been completed.

INTRODUCTION

The purpose of this manual is to provide necessary instructions for operating personnel to operate and maintain the Mark II model of the Laser Absolute Gravimeter (LAG). This manual contains a description of and information regarding its operation, alignment, and maintenance. Additionally, a listing of all drawings required for maintaining the equipment is included.

DESCRIPTION

Mark II Laser Absolute Gravimeter

LAG operates as a dynamic Michelson interferometer to make absolute measurements of gravity accurate to ± 1 part in 10^6 . Basically, monochromatic light from a highly stable helium-neon laser is passed through a beam splitter (Fig. 1) which directs half of the beam to fixed corner cube reflector "A" and half to corner reflector "B," hereafter referred to as "the bird." Both beam halves are reflected back through the beam splitter to a photodetector, producing interference fringes at the detector.

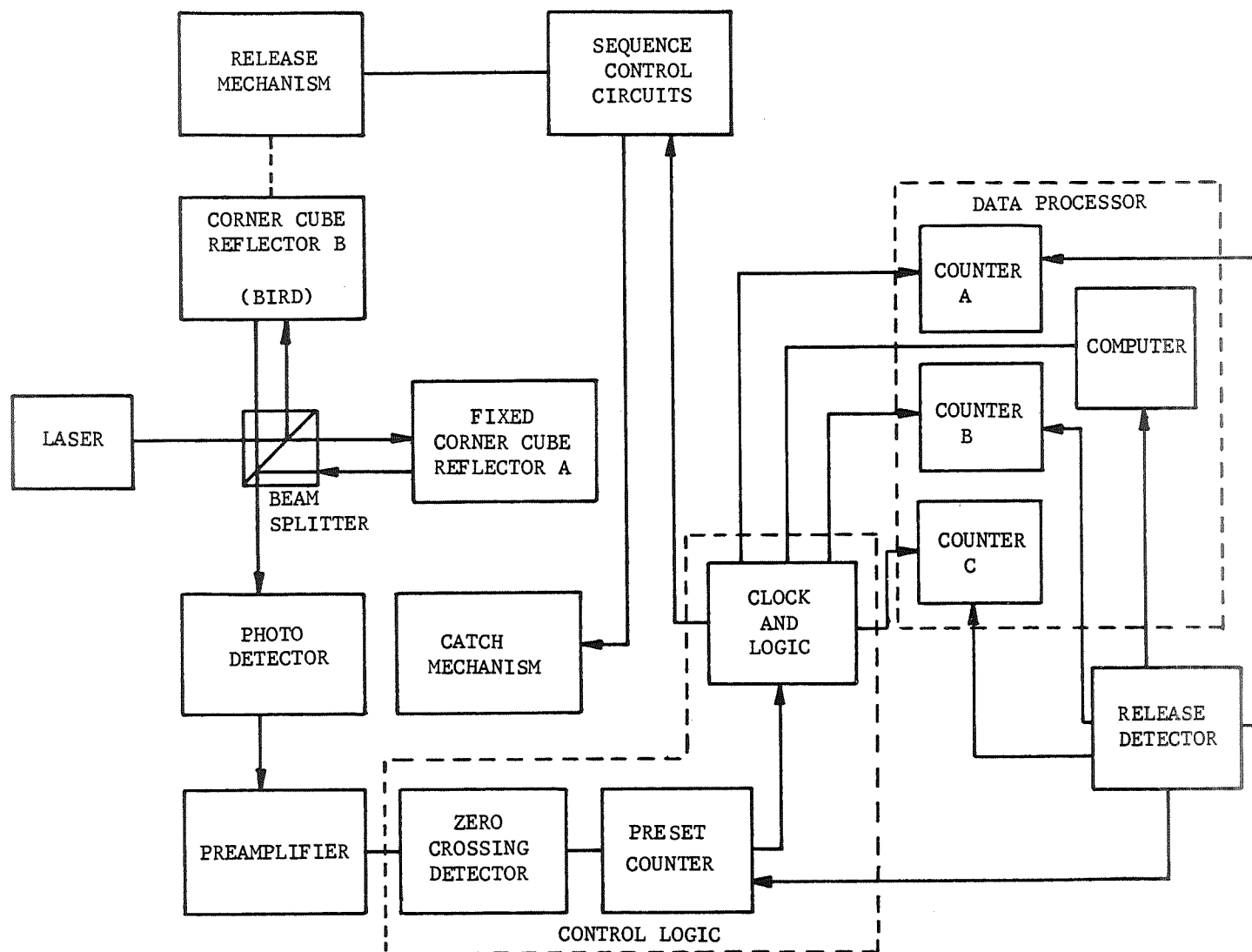


Figure 1. Block diagram LAG.

The mechanical assembly is enclosed in a vacuum chamber to remove the effects of air friction on the acceleration of the falling bird. The vacuum chamber is mounted on an air-supported table which maintains the axis of the chamber on the gravity vector and isolates the assembly from seismic disturbances and from disturbances caused by bird release.

To make the gravity measurement, the bird is first released and allowed to fall freely, therefore becoming the moving mirror of a Michelson interferometer. When the bird is in free-fall, a preset counter is preset with a partial count (delay distance). As the bird falls, interference fringes move across a photodetector and are detected by a zero crossing detector. When the preset counter reaches a full count (n), it generates a start pulse for Counter A and begins counting again. The preset counter is now set to a partial count corresponding to the drop distance being measured. When the preset counter reaches n again, it generates a stop pulse for Counter A and a start pulse for Counter B. Another full count stops Counter B. Counter C is started and stopped in the same manner during a third measuring interval. The bird is then caught by a catch mechanism, is raised to the drop position, and the catcher then returns to the bottom of the drop chamber. The absolute gravity value is a digital output displayed on a system computer. Counters A, B, and C display the measured times taken for the bird to fall through the desired drop distances. The computer reads out a "g" value computed from the measured distances A and B. By using Counter C and a calculator, two "g" values can be computed for each drop.

LASER

The light source used in the LAG is a helium-neon continuous wave laser which emits radiation at a wavelength of approximately 0.633 micron. The emitted power of the unit is 300 microwatts. The light from the laser has a beam divergence of several milliradians. This is further reduced by use of a collimating lens mounted on the laser. In addition, a polarization rotator is mounted on the laser and can be adjusted for best fringe contrast with the system in operation. The laser is capable of frequency stability of ± 1 MHz per day through the use of a servo control system.

OPTICAL SYSTEM

The optical system (Fig. 2) includes all of the components through which the laser beam passes or from which it reflects. After passing through the polarization rotator and collimating lens referred to in the above paragraph, the beam is subjected to a number of divisions and direction changes before reaching the photodetector. These divisions and changes are described as discussed in the following paragraphs.

Beam Splitter. The beam splitter consists of a glass cube made of two wedges cemented together. The beam splitter divides the light beam into two equal intensity beams perpendicular to each other. In this particular design, the reflected beam is directed upward to a mirror that is mounted in the falling bird, and the transmitted beam is directed on its

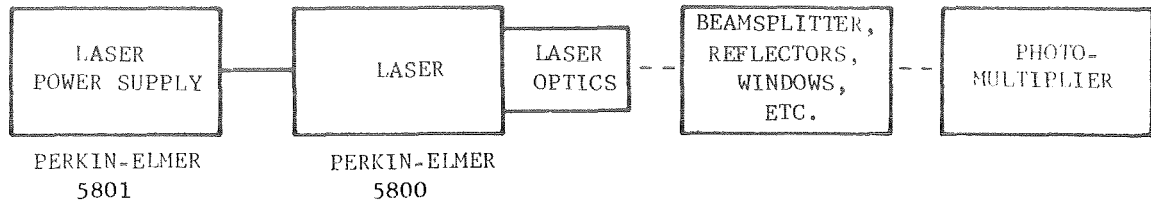


Figure 2. Electro-optical system.

original path to the fixed reflector. The return beams are again split as they pass through the beam splitter the second time. The beam splitter is mounted on an adjustable table to facilitate orientation of the glass cube relative to the laser beam. The table can be moved linearly on a vertical axis, rotated around the same axis, and tilted about any horizontal axis. Tilt adjustment is accomplished by means of two adjustment screws.

Fixed Reflector. The fixed reflector is a corner cube retroreflector. It is mounted in a gimbal assembly permitting two-axis rotation adjustments and linear vertical and horizontal adjustments perpendicular to the laser beam. The reflector returns the beam transmitted from the beam splitter.

Brewster Window. Light enters the vacuum chamber by means of a quartz window inclined at the Brewster angle (55 deg 30 min). This arrangement prevents undesired interference resulting from parallel reflections from the window surface and ensures that most of the incident light is transmitted. The vacuum seal is accomplished by clamping the window mount against an O-ring.

Corner Cube. A corner cube reflector which returns the light beam passing through the Brewster window is mounted in the falling mass (bird). When rotated about an axis passing through the center of the reflector, it will tolerate a few degrees of rotation without attendant angular rotations of the return beam. The light reflected from the corner cube passes back through the Brewster window, through the beam splitter, and onto the photodetector.

BIRD RELEASE AND RECYCLE MECHANISM (Fig. 3)

Bird Mechanical Design. The bird is machined of Delrin AF, which is a high impact strength nonmagnetic material. Its shape is cylindrical with a conical tip which permits it to be easily caught at the conclusion of its fall. The bird has a hole through its center to allow passage of the light beam and engagement with the release mechanism. The bird contains a corner cube retroreflector.

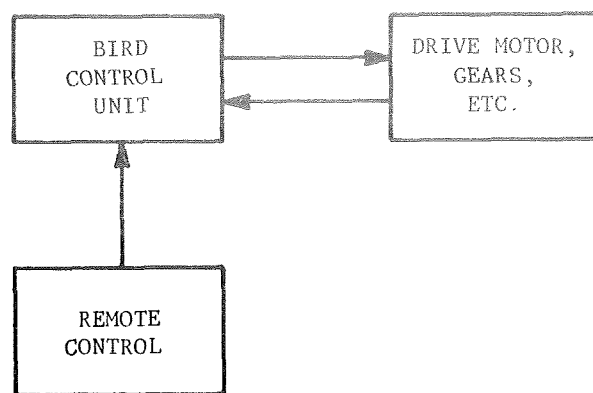


Figure 3. Drive control system.

Release Mechanism. The bird is held in the upper position by two bronze wire springs which grip the sides of the inner concentric hole of the bird. It is positioned above the catcher and properly oriented in rotation about its longitudinal axis by a brass finger. The springs are slowly withdrawn by a hydraulic piston which is initially cocked by the catcher when the bird is raised. No outside influence controls the release, and the design is such that no angular momentum is imparted to the bird at release.

Recycle Mechanism. The recycle mechanism is comprised of the following components: (Figs. 4 and 5)

1. Catcher -- At the conclusion of the drop, the bird falls into the cup-shaped receptacle which is coupled to a ball screw shaft. This catcher is designed to accept the bird upon arrival at various attitudes other than a perfect vertical condition. The cup will rotate about the vertical axis if necessary to reorient the bird.

2. Drive Mechanism -- The drive mechanism consists of a ball shaft which supports the catcher, a shaft seal for entry into the vacuum chamber, a flexible coupling, and a drive motor. Rotation of the drive motor causes the catcher assembly to move up or down the fall path. Rotation of the catcher assembly about the ball screw shaft is prevented by a guide rod in the chamber.

3. Timing Mechanism -- The sequence of events such as stopping or reversing the drive motor is controlled by an auxiliary screw shaft above and outside the vacuum chamber. The shaft is scaled down from the shaft inside the chamber and is driven from the motor shaft by a timing belt. A cam rides on the shaft and moves in a helical path as the motor rotates. Microswitches are located at each end of the cam travel and are triggered at appropriate times to control recycle events. A 20-turn potentiometer, used to vary the speed of the drive motor during the cycle, is also driven by the timing belt.

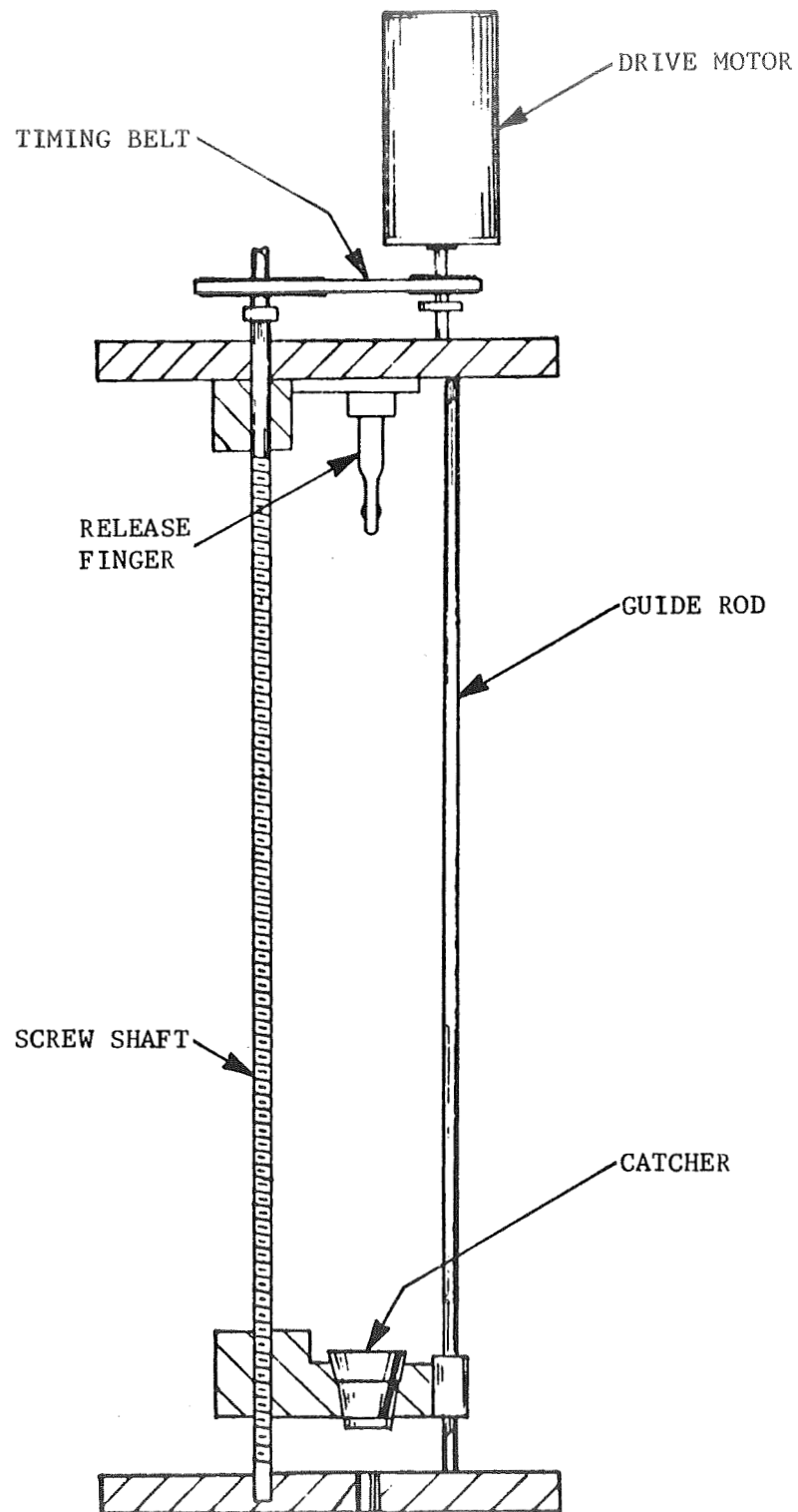


Figure 4. Recycle drive mechanism

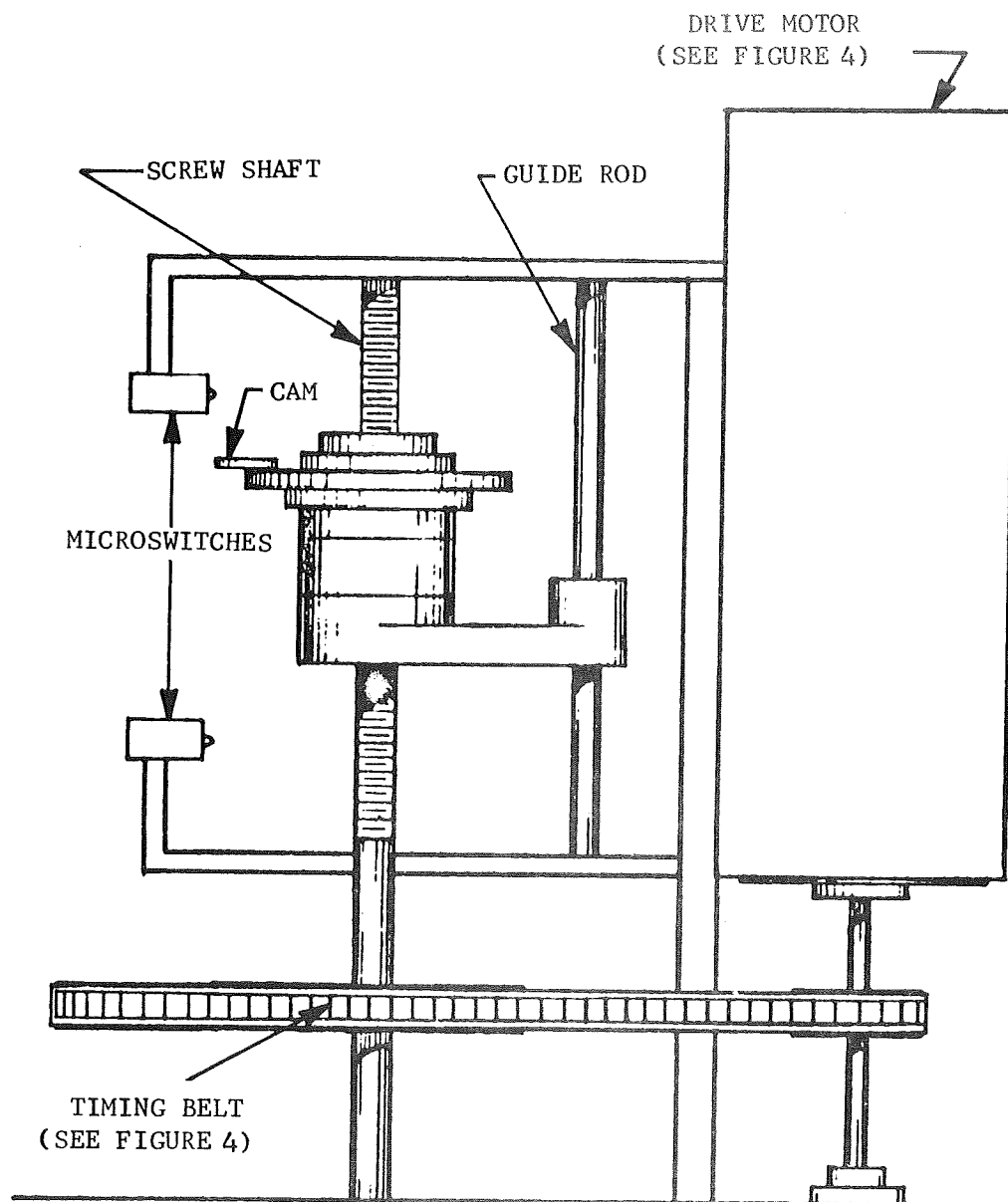


Figure 5. Timing mechanism.

MOTOR CONTROL SYSTEM

Electrical Sequence. Upon actuating the RAISE switch on the motor control panel, a latching relay is operated which applies power to the system. The drive motor is gradually accelerated to return the bird. At the midway point of the lift, the motor speed reaches its maximum and begins to reduce again to a low value at the end of the lift. The motor speed follows a cosine function curve and is controlled by a potentiometer coupled to the motor shaft. The potentiometer varies the input to an amplifier which controls the motor drive voltage. As the carriage reaches the top of the chamber and the bird is in position for rehanging, the carriage cocks the hydraulic release mechanism against a spring, causing the release mechanism to grip the bird. The microswitch also operates another latching relay which reverses the direction of the drive motor. The motor accelerates the carriage down to its waiting position at the bottom of the chamber, at which time the timing cam depresses another microswitch, thereby stopping the motor and removing all electrical power. The system is now reset in preparation for another drop.

Motor Control Panel. The motor control panel contains all of the electrical apparatus for control of the recycle function except for the drive motor, gear assembly, and microswitches located above the drop chamber. The major components of the motor control panel include: (1) dc power supplies, which provide power for the drive motor, amplifier, and the latching relays; (2) amplifier, which controls the speed of the drive motor; and (3) relays which perform switching operations during the recycle sequence.

PNEUMATIC TABLE SUPPORT AND MOTION ISOLATION SYSTEM

The two tables on which most of the LAG subsystems are mounted are each supported by four air columns which are sealed with bellows (Fig. 6). The air pressure in each air column is controlled by a pressure regulator. Raising the table causes a reduction of pressure in the bellows, thus maintaining a constant level varying load on the table. The air suspension also effectively isolates the LAG from seismic vibration and from "jump-up" caused by bird release.

Three transducers are located at key points on the table support system to pick up any table motion and ground seismic vibration. One transducer is located on the top table, one on the bottom table, and one on a table leg (essentially on the ground). Each transducer output is amplified, filtered, and recorded on a strip-chart recorder (Fig. 7). Provisions are made for oscilloscope connections to the output of each amplifier.

LIGHT DETECTION AND AMPLIFICATION

Photomultiplier Module. Light enters the photomultiplier tube through an aperture in the housing. The light then strikes the cathode of the photomultiplier tube which is located within the module. The small current variations generated by the interference fringes are transmitted by a coaxial cable to the signal amplifier. The high voltage supply

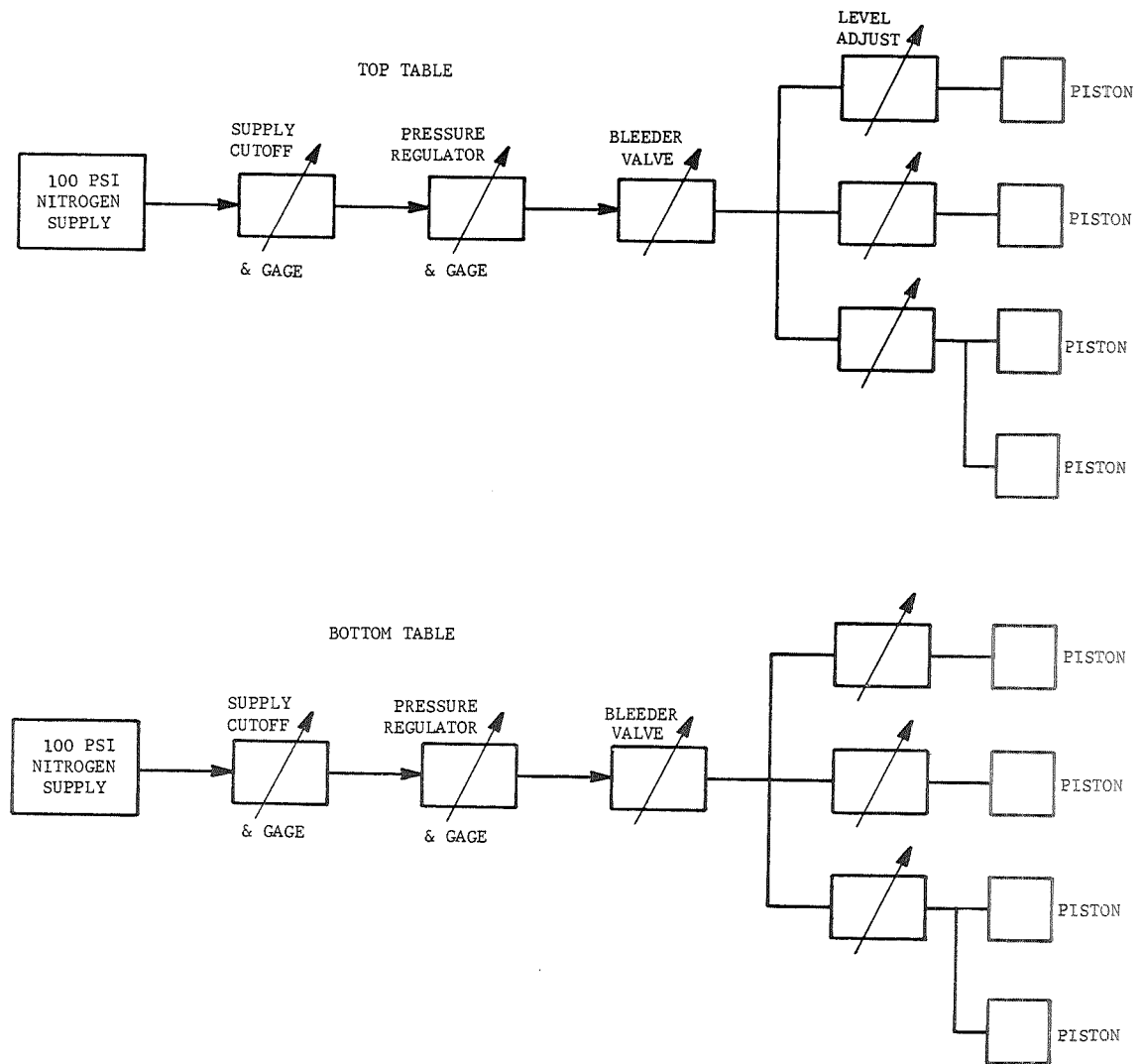


Figure 6. Vibration isolation system.

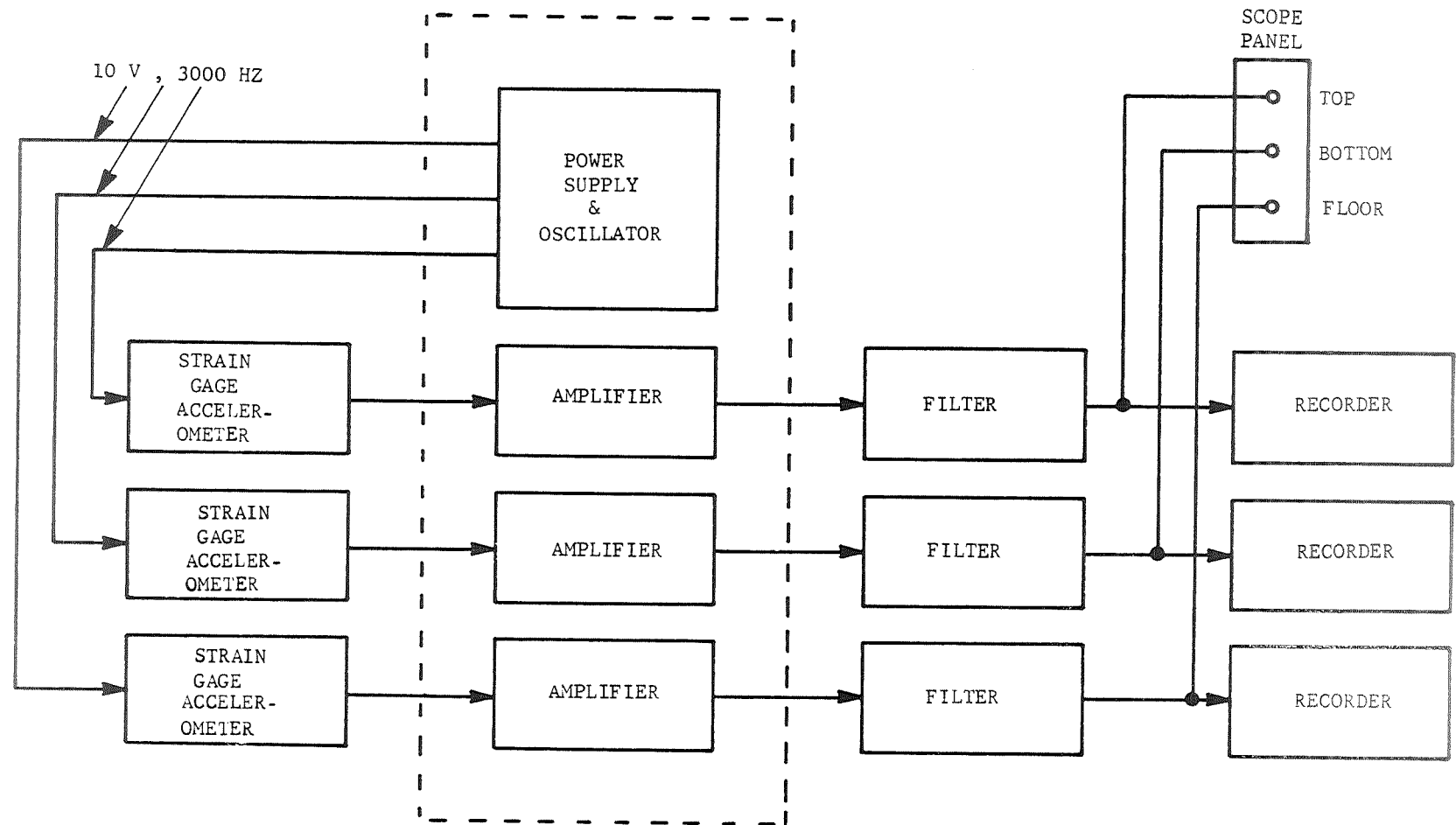


Figure 7. Vibration measuring system.

for the tube is mounted in the instrumentation console in the trailer. The signal amplifier is powered by a +6 Vdc and -6 Vdc battery pack located on the bottom table mount.

Signal Amplifier. The signal amplifier provides approximately 50-db voltage gain for the photomultiplier module output signal. The unit is a commercial wideband amplifier in an integrated circuit modified with an emitter follower output. The amplifier is mounted in the photomultiplier tube housing.

DATA COLLECTION SYSTEM

The data collection system (Fig. 8) measures the time required for the bird to fall through three consecutive, equal distances. This distance is variable. The distance most used is equal to $(2^{19}) \lambda/2$. A two-counter configuration can be used with the B distance either equal to, one-half, or twice the A distance.

NOTE

The present system contains only two-time interval counters, but outputs are available and have been used with a third counter.

An optical release detector system views the bird in the raised position and signals the instant of release as the bird falls past a photocell. This signal is used to reset the preset counter and time-interval counters.

The measurement is preceded by an initial delay distance which does not enter into the equation but which does delay the measurement and permits the bird and the release detector system to stabilize. This distance is variable and depends on the physical position of the photocell and the partial count set in the preset counter.

Time is measured by three, 100-MHz counters whose time base is supplied by a 1-MHz oscillator. Gate pulses to start and stop each counter are supplied by the control logic. The control logic consists of a zero crossing detector, a pulse amplifier, a 20-bit binary counter, a four-state control counter, four output gating circuits, and eight cable drivers. The logic system provides start and stop pulses to the time-interval counters and to the system computer. A pushbutton is provided to manually reset the control logic.

After reset, when enough fringes to fill the preset counter have occurred, the decoder gates the next input pulse to the output driver which feeds a pulse to the start input of Counter A. State 1 is the state in which only A-start pulses are gated through. The same pulse which gated the A-start driver is fed to the state counter, advancing it to State 2. After the bird has fallen through the preset measuring distance, typically 2^{19} (524, 288) fringes later, the binary counter has become "full" again. The next input pulse pulses the Counter A-stop and Counter B-start inputs and advances the state counter to

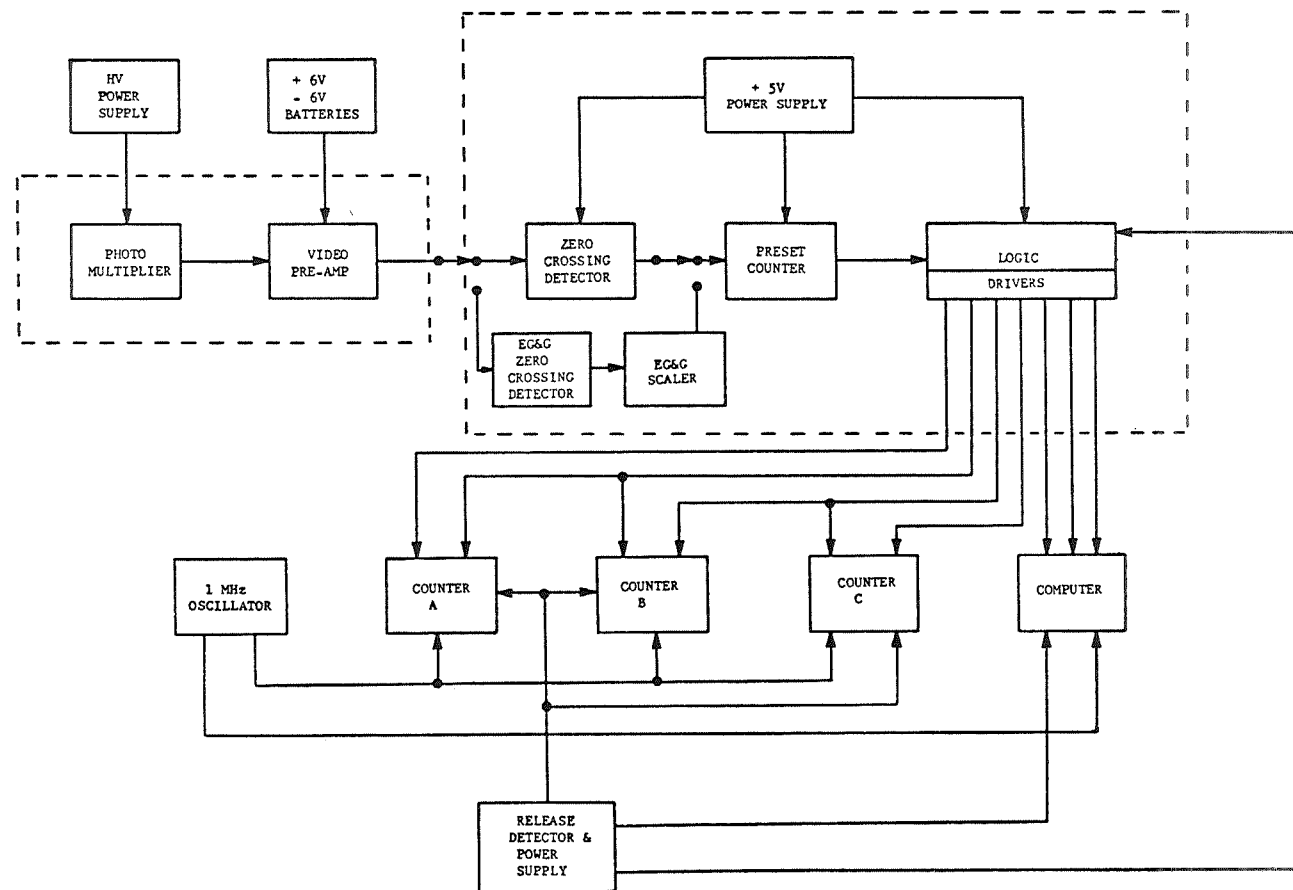


Figure 8. Video and data collection system.

State 3. Again, 2^{19} fringes later, the binary counter is "full," and the next input pulse pulses the Counter B-stop and Counter C-start inputs and resets the state counter to State 4. Counter C is stopped 2^{19} fringes later and the state counter is returned to State 1.

Counters A, B, and C now display the times (to the nearest 10-nanosecond increment) required for the bird to drop through each of three consecutive equal distances.

The zero crossing detector requires a signal of at least 0.5-volt peak at 50 ohms, and will operate at frequencies above 10 MHz. The logic output amplifiers produce a 4- to 5-volt negative-going pulse with a leading edge rise time of approximately 5 nanoseconds for the initial 3 volts, meeting the requirements of the time interval counters.

SYSTEM COMPUTER

The system computer receives the A-start, A-stop, and B-stop pulses (A-stop is the same pulse as B-start). The computer was not designed to operate with three counters. The computer uses different counters than Counters A and B, but counts in the same manner. The computer takes the measured times (A and B), and computes a "g" value. This value is displayed on the front of the computer.

VACUUM SYSTEM

The vacuum system (Fig. 9) consists of the drop chamber, which is to be evacuated, a roughing rotary pump for the initial pumping from atmospheric pressure, an ion pump for obtaining the final vacuum, the ion pump power supply and water cooler subsystems, and a control unit for the thermocouple and ionization vacuum gauges. The roughing pump alone is capable of producing a vacuum of 10^{-3} to 10^{-4} torr. The ion pump is ultimately capable of 10^{-7} torr in LAG operation. Operation of the thermocouple and ion gauge is explained in the manufacturer's manual. All seals in the drop chamber are by O-rings designed for high vacuum service. These are located at the three main chamber flanges, two viewing windows, the Brewster angle window, and the shaft seal.

OPERATION

This section contains operating instructions for LAG. In addition, information on evacuating the vacuum chamber and pressurizing the vacuum chamber to normal atmospheric pressure is included.

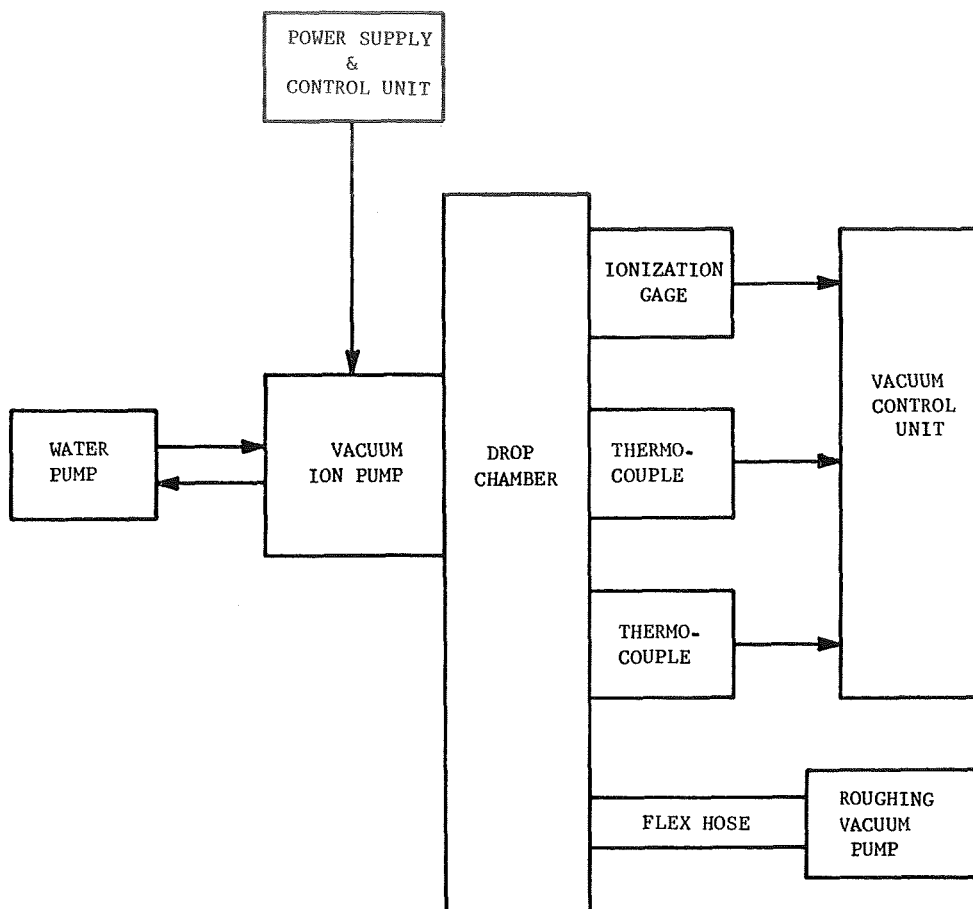


Figure 9. Vacuum system.

Operating Instructions

VIBRATION ISOLATION SYSTEM

Preparation for Use. To connect and activate the vibration isolation system for the LAG tables, perform the following steps:

NOTE

This procedure applies to both tables. However, the top table should be raised first.

1. Connect the table air hose to the outlet of regulator R1 (Fig. 10).
2. Set regulator R1 fully counterclockwise. Verify that valve V1 is closed (fully clockwise).
3. Set regulator R2 fully clockwise.
4. Turn valve V1 several turns counterclockwise. Gauge G1 will indicate the bottle pressure.
5. Turn regulator R1 clockwise until gauge G2 indicates 40 psi for the bottom table or 60 psi for the top table. Allow several minutes for the table to rise and stabilize.
6. Adjust regulator R1 to change table height. The bottom table should clear each leg support by a minimum of one-eighth inch. The top table should clear the top of the bottom chamber by a minimum of one-fourth of an inch.
7. Table tilt is adjusted using the regulators under three corners of the table. Regulators R2 and R3 each regulate the pressure in one leg. Regulator R4 regulates the pressure in two legs. Table inclination should be set to the predetermined values.

Shutdown Procedure. To disconnect and deactivate the vibration isolation system for the LAG tables, perform the following steps:

NOTE

This procedure applies to both tables. However, the bottom table should be lowered first.

1. Set valve V1 fully clockwise.
2. Set regulators R1 and R2 fully counterclockwise.
3. Disconnect hose from the outlet of regulator R1.

LAG OPERATIONAL PROCEDURE

The following paragraphs give the instructions necessary to energize, make the gravity measurement, and deenergize the LAG.

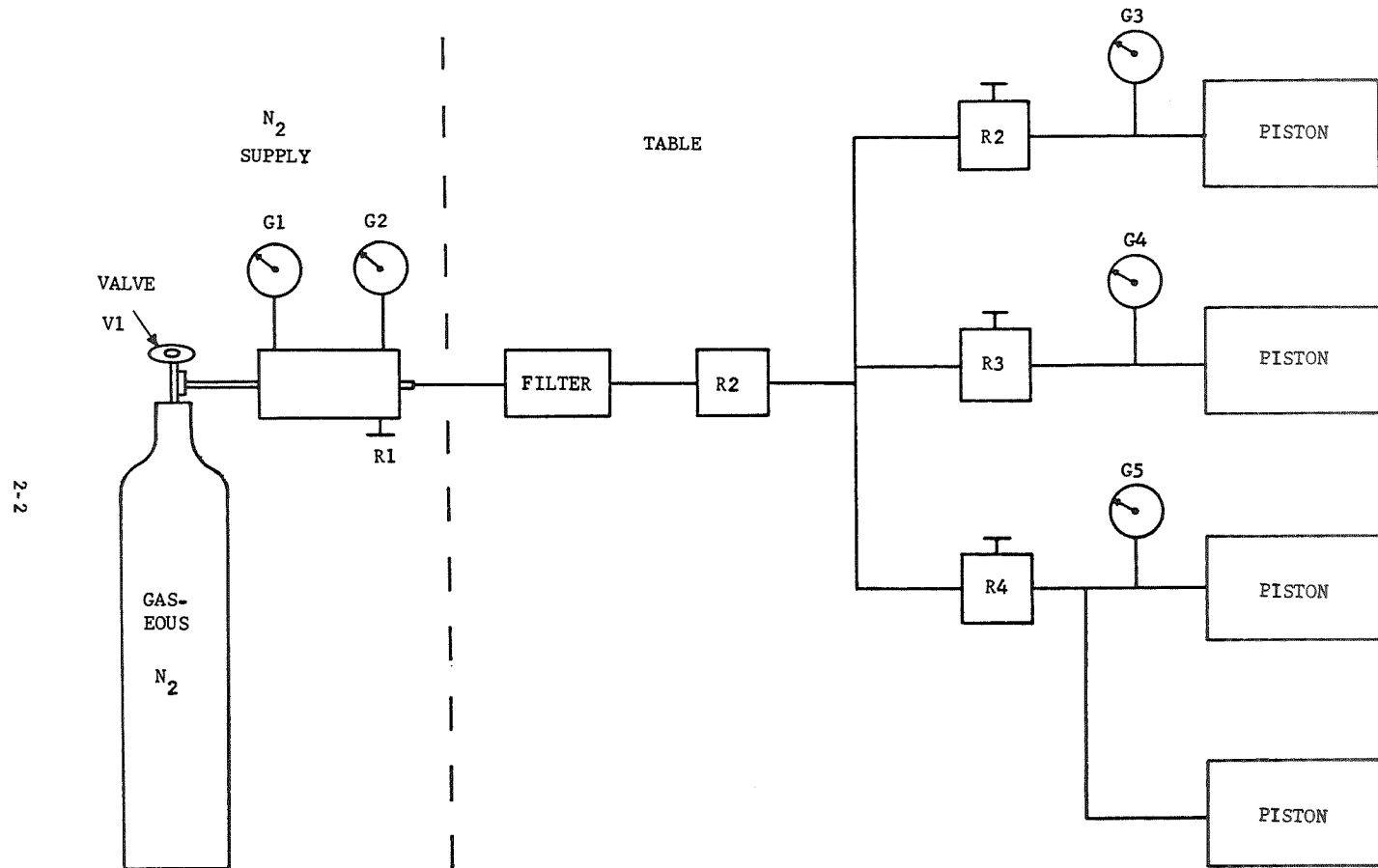


Figure 10. Vibration isolation system for either table.

TURN-ON PROCEDURE

Instrumentation Trailer. Energize the following equipment:

1. System 1 MHz oscillator. (This item should be energized at all times.)
2. Voltage regulator.
3. EG&G zero crossing detector (if used).
4. Release detector.
5. Logic unit.
6. Oscilloscope.
7. Programmable desk calculator or system computer.
8. Time interval Counters A and B.
9. Photomultiplier high-voltage power supply.
10. Vacuum gauge.
11. Seismic system (if used).
12. Bird control unit.

Drop Chamber Area. Perform the following steps:

1. Vacuum pump and laser "line" should remain on.
2. Press "high-voltage" and "start" pushbutton on the laser.
3. Energize the video preamplifier.
4. Energize the oscilloscope.

Preliminary Adjustments. Perform the following adjustments before operating the LAG:

1. If the top table is air supported, check inclination angles of the table with predetermined values. Adjust if different by more than ± 0.5 arc minute.

2. The bottom table should be level within ± 2 arc minutes. Step 3. will compensate for small inclination errors.

3. Raise the bird and check for "no-walk" condition when it falls. If "walk" is significant, readjust the optics. (Refer to Optical Alignment section of this report.)

4. Allow 30 minutes warmup time before proceeding.

5. Check voltages on the video preamplifier. The voltages should be at least +6 and -6 Vdc.

6. Set the photomultiplier high voltage between -1100 and -1300 Vdc, depending on laser power, detector, detector aperture, etc. Other voltage settings may be used for best results if any of the LAG's apparatus is changed. The polarity switch should be in the minus position making the high voltage negative with respect to supply ground; the polarity switch should never be changed when the supply is energized. The video signal should be at least 1-volt peak in the measuring interval.

7. Check the fringe pattern visually and position the detector pickup approximately in the center of one segment. Other segments may be tried for best video.

8. Adjust the laser cavity for autolock operation if desired. The cavity adjustment should be checked at about 30-minute intervals during operation.

9. Check for zero crossover in the zero crossing detector and adjust (refer to the ZCD Alignment paragraph of this report) if triggering does not occur within ± 5 nanoseconds of zero crossover. Recheck about every hour for drift.

10. Test the logic and counters with the system's 1-MHz oscillator and test circuit. The counters should read out times equivalent to the number of fringes (drop distance) selected.

11. Check the seismic outputs if used.

12. Check the vacuum in the drop chamber. (Refer to the Vacuum Chamber Evacuating and Pressurizing section of this report.)

Operation. To operate the LAG, perform the following steps:

1. Assure that all cables are properly connected.

2. Check video on the oscilloscope. Video should be at least 1-volt peak during measuring interval. Trigger the oscilloscope externally with the reset pulse from the release detector to observe the video.

3. Set the delay and measuring distance to the desired values. Switches are located on the rear of the logic unit.

4. Raise the bird. The release detector light should come on.

5. When the bird falls, the release detector light should go off and counters should read out the two measured drop-times.

6. A programmable desk calculator is used to compute the measured "g" value. The program is stored on a magnetic card. The system computer may be used but has been unreliable.

7. Repeat steps 4, 5, and 6 for as many drops as required.

TURN-OFF PROCEDURE

Instrumentation Trailer. De-energize the following equipment:

1. Logic unit.
2. Counter A.
3. Counter B.
4. Release detector.
5. Bird control unit.
6. Oscilloscope.
7. Photomultiplier high-voltage supply.
8. Seismic system.
9. Vacuum gauge.
10. Programmable desk calculator or system computer.
11. EG&G power supply.
12. Voltage regulator.

NOTE

Leave 1-MHz oscillator energized.

Drop Chamber Area. De-energize the following equipment:

1. Video preamplifier.
2. Oscilloscope.
3. Laser high voltage. Leave laser on "line" and vacuum pump on.

Vacuum Chamber Evacuating and Pressurizing

High vacuum systems require extra care in standards of cleanliness when handling components which will be subjected to vacuum conditions. Contaminants which affect the efficiency of the vacuum pumps may be transmitted by the hands, tools, or materials used inside the drop chamber. Atmospheric constituents, particularly argon gas, may also contaminate the vacuum system. Therefore, it is desirable that vacuum be maintained at all times. When the vacuum chamber is open to the atmosphere for the short periods that are sometimes required, a continuous purge of the system with dry nitrogen gas is recommended. Tools and components used in the chamber should be thoroughly cleaned prior to use to remove oils and other substances which may outgas under high vacuum conditions. Hands that touch vacuum components should be covered with lint-free gloves.

EVACUATING THE CHAMBER

To evacuate the drop chamber, perform the following steps:

1. Close the Brewster window, master valve (clockwise rotation until tight, 2 to 3.5 kilogram-meters), and viewing ports.
2. Disconnect purge line from master valve and shut off purge gas supply.
3. Connect roughing pump hose to master valve and turn roughing pump on. Check the oil level in the roughing pump while the pump is running. Allow the roughing pump to run 2 minutes before proceeding.
4. Slowly open the master valve (counterclockwise rotation) until the roughing pump begins to labor. Stop opening the master valve until the roughing pump smooths out. Continue opening the master valve slowly until fully open, making the motion slow enough that the roughing pump does not labor excessively. At this point, the roughing pump can be left on indefinitely to maintain a vacuum of about 10^{-3} torr in the chamber.

5. Check the vacuum in the chamber. At a pressure of about 5×10^{-3} torr as indicated by either the thermocouple gauge or ionization gauge, the ion pump can be turned on to supplement the roughing pump. Do not use the ionization gauge when the thermocouple gauge indicates pressure above 10×10^{-3} torr.

6. The following procedure should be followed to operate the ion pump:

- a. Set start-run selector switch to start.
- b. Set high-voltage control to zero.
- c. Set filament switch to off.
- d. Set emission control to zero.
- e. Set power switch to off.
- f. Press high-voltage reset pushbutton.
- g. Set bias control to zero.

WARNING

The voltage and currents available from the Orb-Ion pump power supply can be lethal if misused. Proper care and caution must be exercised at all times.

h. Ensure that the pump power cable to the Orb-Ion pump is connected and that the pump and pump control unit have a common ground.

i. Set filament switch in rear of chassis to SERIES. (Parallel position if one filament is open.)

j. Connect the 115-Vac power cable to wall outlet.

NOTE

The Orb-Ion pump can be started at 10^{-2} torr or below. If the indicated pressure is 5×10^{-3} torr (5μ) or lower, perform steps (11) through (21). However, when difficulty is experienced in starting the pump in the "run" position due to pressures above 5×10^{-3} torr, perform steps 7.a through 7.k.

- k. Set start-run selector switch to the run position.
- l. Set high-voltage control to zero (completely counterclockwise).
- m. Set main power switch to on.
- n. Set filament switch to on.
- o. Turn high-voltage control slowly clockwise and observe the meter. The filament light will illuminate after the high-voltage control has been turned half way. Advance the high-voltage control a little beyond the point where the filament light illuminated. This should be approximately 7 on the dial.
- p. Turn emission control clockwise until the meter indicates 10 milliamperes on the green scale. Let the pump remain at this setting for approximately 2 minutes. Advance the emission control in 10-milliamperes steps with 2-minute waiting periods until the meter indicates 40 milliamperes.
- q. Slowly turn high-voltage control clockwise in conjunction with emission control adjustment to obtain desired reading on meter.

NOTE

The setting of 40 milliamperes should be the upper operation limit to allow for current surges on power line. Should the pointer suddenly overshoot and the circuit breaker open, return the high-voltage control to zero before resetting circuit breakers. Then repeat steps o., p., and q. Do not reset the emission control.

r. Readjustment of the emission and high-voltage controls will be necessary as the vacuum changes. The current should be maintained at 40 milliamperes and adjusted for maximum pumping speed.

s. Adjust the bias control clockwise to $3\frac{1}{2}$ for titanium evaporation. Optimum position may be determined by observing the pressure gauge and adjusting for lowest pressure reading after chamber pressure has reached the 10^{-7} torr range.

t. Very slowly turn on the cooling water to the pump body. If the high voltage reset opens persistently, check the system pressure and start the ion pump in the start position as outlined in steps 7.a through 7.j.

7. When difficulty is experienced in starting the Orb-Ion pump in the run position because of high pressure (5×10^{-3} torr or higher), the pump should be started in the start position with the water supply turned off.

- a. Set the start-run selector switch to start position.
- b. Set main power switch to on (red light will illuminate).
- c. Set filament switch to off.
- d. Set emission control to zero.
- e. Set bias control to zero.
- f. Slowly turn high-voltage control clockwise and observe the meter. The pointer of the meter will move to the left (red scale). Increase the high voltage until the meter indicates 50 milliamperes.

NOTE

There is now a glow discharge inside the pump and the anode is being outgassed. As the pressure is decreasing the meter current will also decrease.

- g. Should the meter indicate above 50 milliamperes, reduce the high voltage to reduce current.
- h. If the high-voltage reset drops out, set the high-voltage control to zero, reset and start again, slowly increasing the high-voltage control as outlined in steps f. and g.
- i. As the system is pumped down, the meter current will decrease and finally the discharge will be extinguished.

NOTE

If the current does not decrease after approximately 15 minutes, check the system for leaks.

- j. Set high-voltage control to zero and the main power switch to off.
- k. Turn on cooling water and repeat steps 6.a through 6.t.

NOTE

The control unit is designed to provide 10 percent more power output to allow for line voltage which may drop below 117 Vac. To check the voltage output of 9 to 10 kilovolts and 30 to 40 milliamperes, a 20 000-ohm/volt multimeter should be used to check the output voltage at the rear of the control unit. Voltage between test points TP1 and TP2 should be between 9 and 10 Vdc (TP2 is positive run position), indicating 9 to 10 kilovolts in the high-voltage output.

8. After full pumping power has been achieved and the pressure is 8×10^{-5} torr and dropping in the chamber, close the master valve fully clockwise to approximately 2 to 3.5 kilogram-meters. This separates the vacuum chamber from the roughing pump. The ion pump should take over at this pressure and pump the chamber down to between 10^{-6} and 10^{-7} torr.

9. Leave the ion pump on indefinitely to maintain a high vacuum. Set the emission current at 32 milliamperes.

OPENING CHAMBER TO ATMOSPHERE

To open the vacuum chamber to the atmosphere, perform the following steps:

1. Set the master valve fully clockwise.
2. Turn off the roughing pump (if running) and the ion pump. Turn off the ionization gauge. Turn off the cooling water supply and allow the ion pump to cool for 10 minutes before opening the chamber to the atmosphere.
3. Remove the roughing pump hose from the master valve.
4. Loosen the mounting screws on one of the viewing ports so that the aluminum retainer ring rattles slightly.
5. Open the purge supply valve and regulate the pressure (~ 2 psi) so that a slight flow of nitrogen is obtained. Connect the purge line to the master valve.
6. Slowly crack the master valve open, allowing the purge gas to bleed slowly into the chamber. When the chamber is at atmospheric pressure, the previously loosened viewing port will rattle against the chamber. Either viewing port can then be removed for work or

inspection inside the chamber. Only one viewing port should be removed at any one time unless the work requires that both be open. The chamber should be closed and evacuation started as soon as work inside the chamber is completed.

PRINCIPLES OF OPERATION

This section contains the principles of operation for certain units of the LAG. Refer to the applicable manufacturer's instruction manual for information on units not contained in the section.

Motor Control Unit

The motor control unit provides the sequenced switching and control voltages to raise and lower the bird catcher.

When the catcher is down (normal position), the top microswitch (S2) on the motor gear assembly is closed. Relays K3 and K4 are latched in the positions shown on the schematic. (Refer to motor control unit schematic in the Appendix.) Relay K2 is normally closed in the positions shown on the schematic. No ac voltage is applied to the printed circuit board (PCB), which contains a dc power supply and part of the motor control circuitry.

When the raise switch S1 is pressed, the coils of relays K2 and K3B are energized. Relay K2 remains energized as long as the switch is held in the on position. Relay K3 latches in the position opposite that shown on the schematic. The motor will have a small voltage applied. Potentiometer R21, which is geared to the motor drive mechanism, produces a control voltage which is dependent on the position of the catcher. This voltage is minimum when the catcher is at the top or bottom of the chamber and maximum when the catcher is midway between top and bottom. The catcher starts to rise and switch S2 opens.

Switch S1 is released (opened). Relay K3 is latched so ac voltage is still fed to the PCB. A dc voltage (approximately 140 volts) is now fed to the common sides of switches S2 and S3; however, both of these switches are open while the catcher is rising. A combination of the generator voltage and the voltage across resistor R21 controls the motor speed. As the catcher approaches the top of the chamber the motor slows down.

When the catcher rises just enough to latch the bird onto the release mechanism, the bottom microswitch (S3) closes. Relay K4A is energized and relay K4 latches to the position opposite that shown on the schematic. Relay K4 reverses the polarity of the voltage fed to the motor, reversing the direction of the motor rotation, which causes the catcher to descend.

After the catcher reaches its "down" position, switch S2 closes, energizing relays K3A and K4B. Relays K3 and K4 are latched in the positions shown on the schematic. Relay K3 breaks the ac voltage supply to the PCB and also the dc voltage to the motor. Relay K4 reverses the motor leads and also the generator leads. Thus, when switch S1 is closed again, the motor will drive the catcher up and the generator will provide the correct polarity voltage to the control circuitry on the PCB.

After the bird falls, the cycle can be repeated by pushing the raise switch. A parallel remote raise switch is located in the drop chamber shed. Either this remote switch or the one located on the control unit will activate the system. The stop-go switch will stop the catcher at any point in the cycle. A remote stop-go switch is located on the same box as the remote raise switch. Both stop-go switches must be closed for the motor to operate.

Release Detector

The release detector detects the instant the bird is released from its raised position. This detection is used to reset the preset counter and time interval counters.

When the bird is in the raised position, the light emitted by L1 (Figs. 11 and 12) is blocked and cannot strike the mirror that is located on the opposite side of the chamber. Consequently, the level of the reflected light incident on the base of phototransistor MRD 300 is only sufficient to allow a very small current to flow; therefore, the base of transistor Q1 remains essentially common. Transistor Q2 is held on by the voltage potential on the wiper of potentiometer R5. This voltage is normally set between 1.5 and 2.0 Vdc. With transistor Q2 conducting, current limiting diode CL1020 limits the current flowing through transistor Q2 to 1 milliamperes, setting the collector voltage of transistor Q2 at 2.6 volts. This is not sufficient to break down zener diode CR3; therefore, transistor Q4 is off and a high level is applied to the input of the lamp driver. The high level at the input to the lamp driver turns it on and the lamp annunciates that the bird is in the raised position.

The output of transistor Q4 and the binary latch (NAND gates G3 and G4) is capacitively coupled to the inputs of NAND gate G1. The two 10 000-ohm resistors connected to the inputs of NAND gate G1 are large enough so that the current flowing from the input drops a voltage greater than the 1-volt threshold, causing the inputs to NAND gate G1 to be high. The output of NAND gate G1 is low, causing the output of NAND gate G2 to be high regardless of the level of the logic control line. The output of monostable multivibrator OS1 is low which causes the outputs of all reset drivers to be high. The output of OS1 is adjustable from 50 to 150 microseconds by a potentiometer located on the front panel.

When the bird is released, the light from L1 is reflected off the mirror and the intensity incident on the base of the phototransistor is sufficient to cause current to flow, raising the voltage at the base of transistor Q1 above 2 volts. At the threshold, the voltage

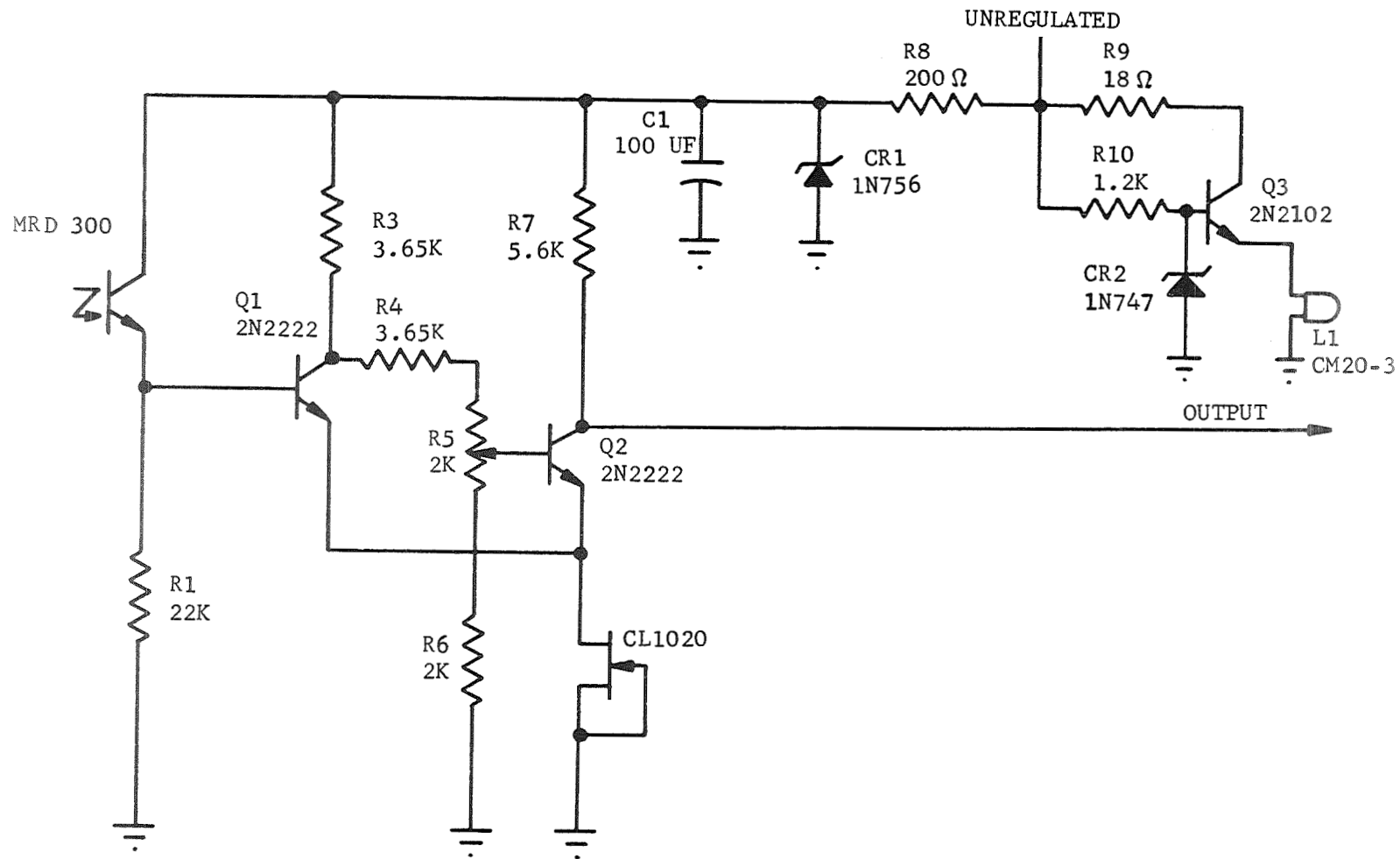


Figure 11. Schmidt trigger schematic.

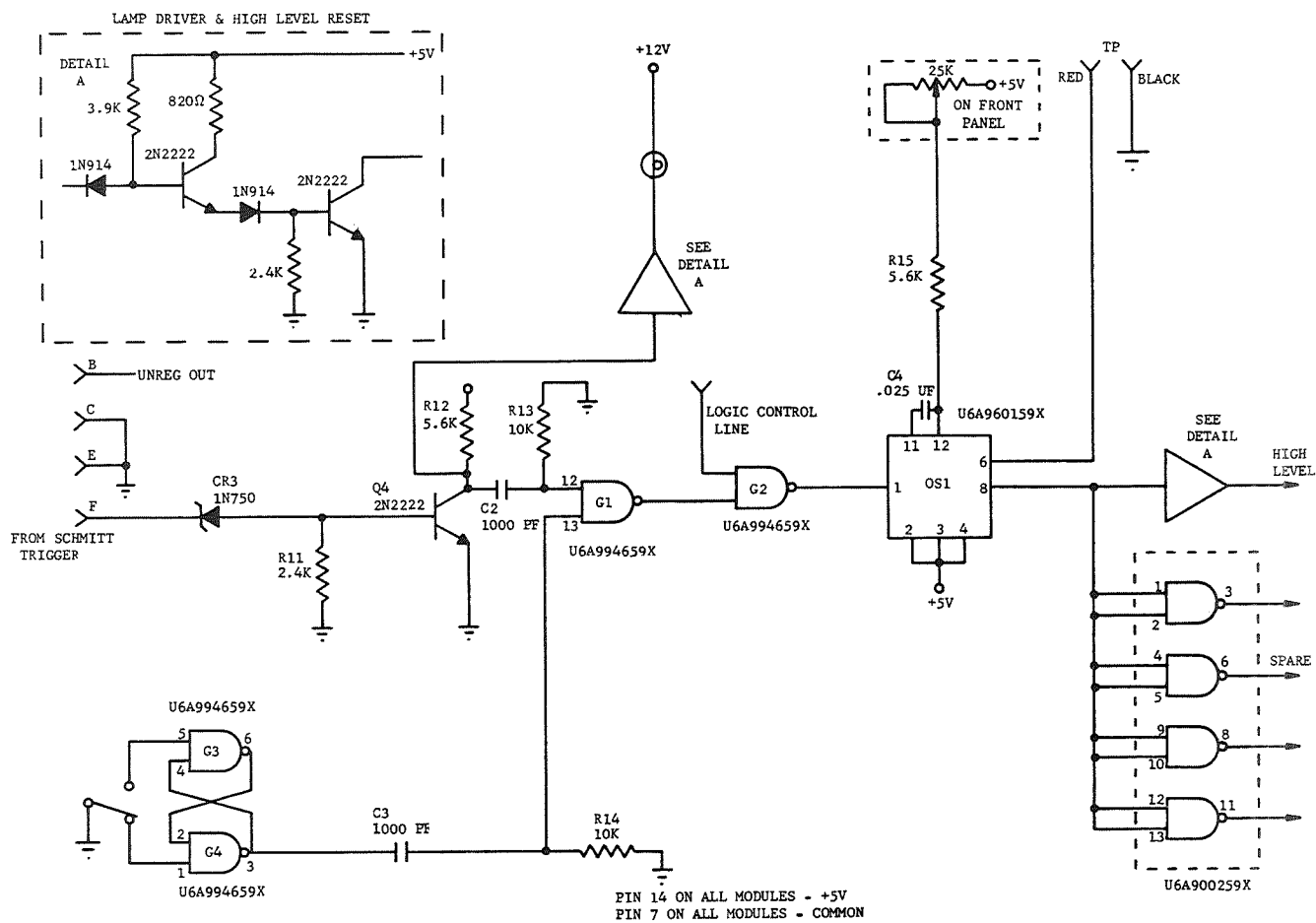


Figure 12. Release detector logic diagram.

on the emitters of transistors Q1 and Q2 goes more positive than the base of transistor Q2. This causes the 1 milliamperes allowed by current limiting diode CL1020 to rapidly switch from transistor Q2 to transistor Q1. The additional current flowing through resistor R3 lowers the potential across resistors R4, R5, and R6; therefore, less current flows through them. This causes a lower potential to be present at the base of transistor Q2, further aiding in holding it off.

When transistor Q2 turns off, the potential on the collector goes high, causing zener diode CR3 to break down, turning transistor Q4 on. The negative transition caused by transistor Q4 turning on is coupled to the input of NAND gate G1, causing its output to go high. If the logic control line is also high, the output of NAND gate G2 will go low, firing monostable multivibrator OS1.

The positive-going pulse from OS1 is inverted by the reset drivers, causing their outputs to go low for the selected duration of time.

Monostable multivibrator OS1 can also be fired from a pushbutton switch on the front panel for test purposes. The switch contacts are buffered by a binary latch (NAND gates G3 and G4) to prevent OS1 from being fired by contact bounce.

When the output of transistor Q4 goes low, the lamp driver is turned off and the "bird up" lamp is extinguished. The output of transistor Q4 remains low until the bird is raised and the light no longer strikes the base of the phototransistor, causing the Schmidt trigger to return to its quiescent state, turning off transistor Q4.

Logic Unit

The logic unit consists of a housing, a 5-Vdc power supply, and assorted logic cards, all manufactured by the Digital Technology Corporation. The basic blocks of the logic unit (Fig. 13) are a zero crossing detector, a fringe counter, a state counter NAND gates, and cable drivers.

The logic unit counts a predetermined number of fringes (which corresponds to a specific distance) and provides pulses to start and stop the time-interval counters and system computer.

Table 1 and Figure 14 contain waveforms taken at key test points on the logic unit. (Refer to the logic unit in the Drawings and Diagrams section of this report for the location of these test points.)

NOTE

All waveforms are taken with the system set for 2^{15} delay distance and 2^{18} measuring distance. Voltage range of the logic waveforms is 0 to 5 Vdc.

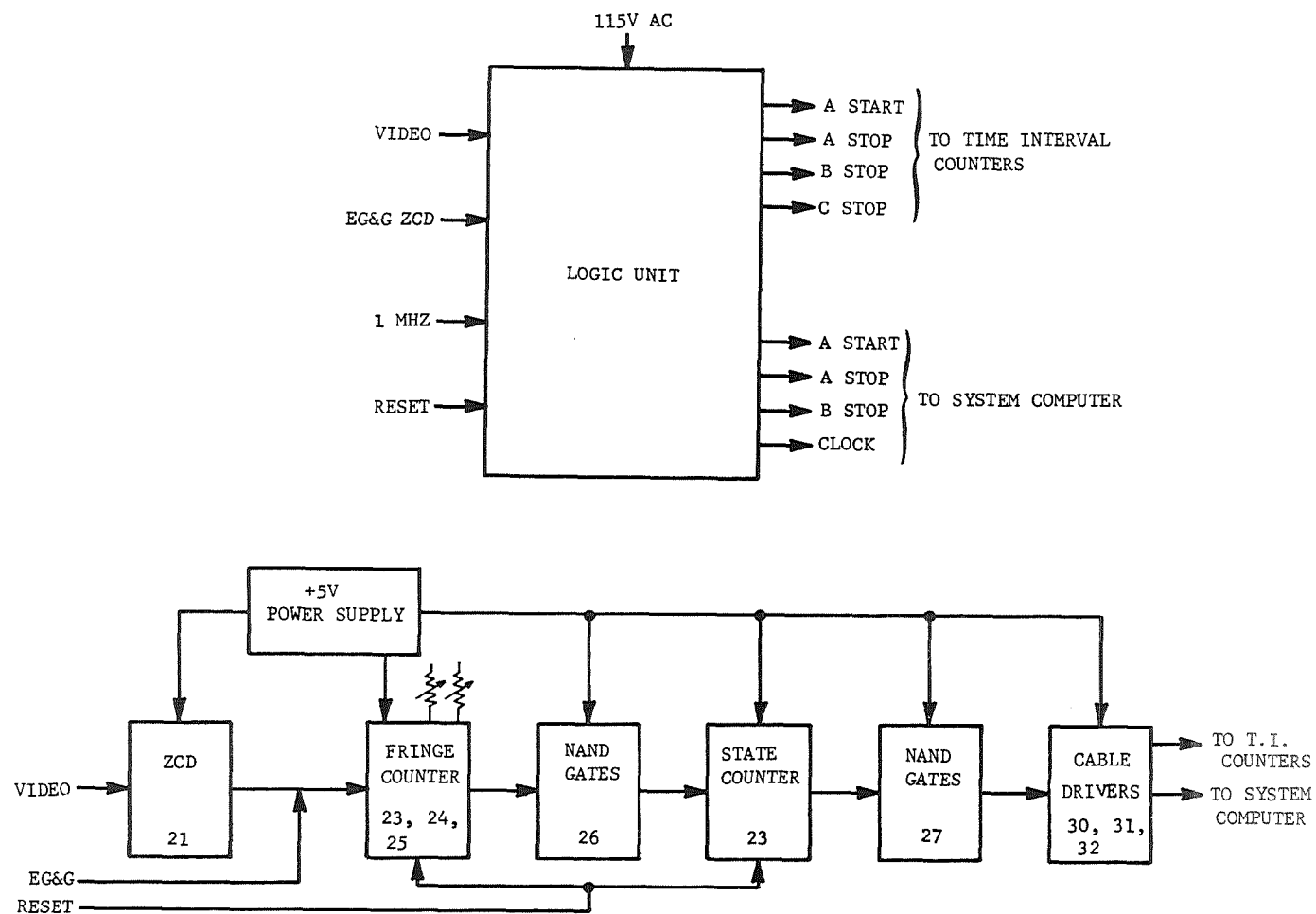


Figure 13. Logic unit.

TABLE 1. LOGIC UNIT WAVEFORMS (NEGATIVE
TRIGGER MODE/SLOPE

Waveform No.	Test Point	Oscilloscope Settings		Trigger Source	Remarks
		Volts/cm	Time/cm		
1	21-3	0.5	0.5 μ sec	TP-23-3	1 MHz Signal
2	21-5	1.0	0.5 μ sec	TP-23-3	Pulse Amplifier Output
3	21-9	5.0	0.5 μ sec	TP-23-3	Pulse Amplifier Output
4	23-1	5.0	2 μ sec	TP-24-1	Fringe Counter Stage 1
5	23-2	5.0	2 μ sec	TP-24-1	Fringe Counter Stage 2
6	23-3	5.0	2 μ sec	TP-24-1	Fringe Counter Stage 3
7	23-4	5.0	2 μ sec	TP-24-1	Fringe Counter Stage 4
8	24-1	5.0	10 μ sec	TP-23-1	Fringe Counter Stage 5
9	24-2	5.0	10 μ sec	TP-23-1	Fringe Counter Stage 6
10	24-3	5.0	10 μ sec	TP-23-1	Fringe Counter Stage 7
11	24-4	5.0	10 μ sec	TP-23-1	Fringe Counter Stage 8
12	24-5	5.0	0.5 msec	Internal	Fringe Counter Stage 9
13	24-6	5.0	0.5 msec	Internal	Fringe Counter Stage 10
14	24-7	5.0	0.5 msec	Internal	Fringe Counter Stage 11
15	24-8	5.0	0.5 msec	Internal	Fringe Counter Stage 12
16	25-1	5.0	5 msec	Internal	Fringe Counter Stage 13
17	25-2	5.0	5 msec	Internal	Fringe Counter Stage 14
18	25-3	5.0	5 msec	Internal	Fringe Counter Stage 15
19	25-4	5.0	5 msec	Internal	Fringe Counter Stage 16
20	25-5	5.0	50 msec	Internal	Fringe Counter Stage 17
21	25-6	5.0	50 msec	Internal	Fringe Counter Stage 18
22	25-7	5.0	50 msec	Internal	Fringe Counter Stage 19
23	25-8	5.0	50 msec	Internal	Fringe Counter Stage 20
24	26-1	5.0	0.5 μ sec	TP-27-7	NAND Gate Output When First 12 Stages are Full
25	26-3	5.0	0.5 μ sec	TP-27-7	NAND Gate Output When Stages 13 Through 20 Are Full
26	26-4	5.0	0.5 μ sec	TP-27-7	NAND Gate Output When All Stages Are Full
27	26-5	5.0	0.1 sec	Reset	State Counter Stage 1
28	23-6	5.0	0.1 sec	Reset	State Counter Stage 2
29	23-7	5.0	0.1 sec	Reset	State Counter Stage 3
30	Video	1.0	50 msec	Reset	Video During Drop
31	23-5	5.0	50 msec	Reset	State Counter Stage 1 During a Drop

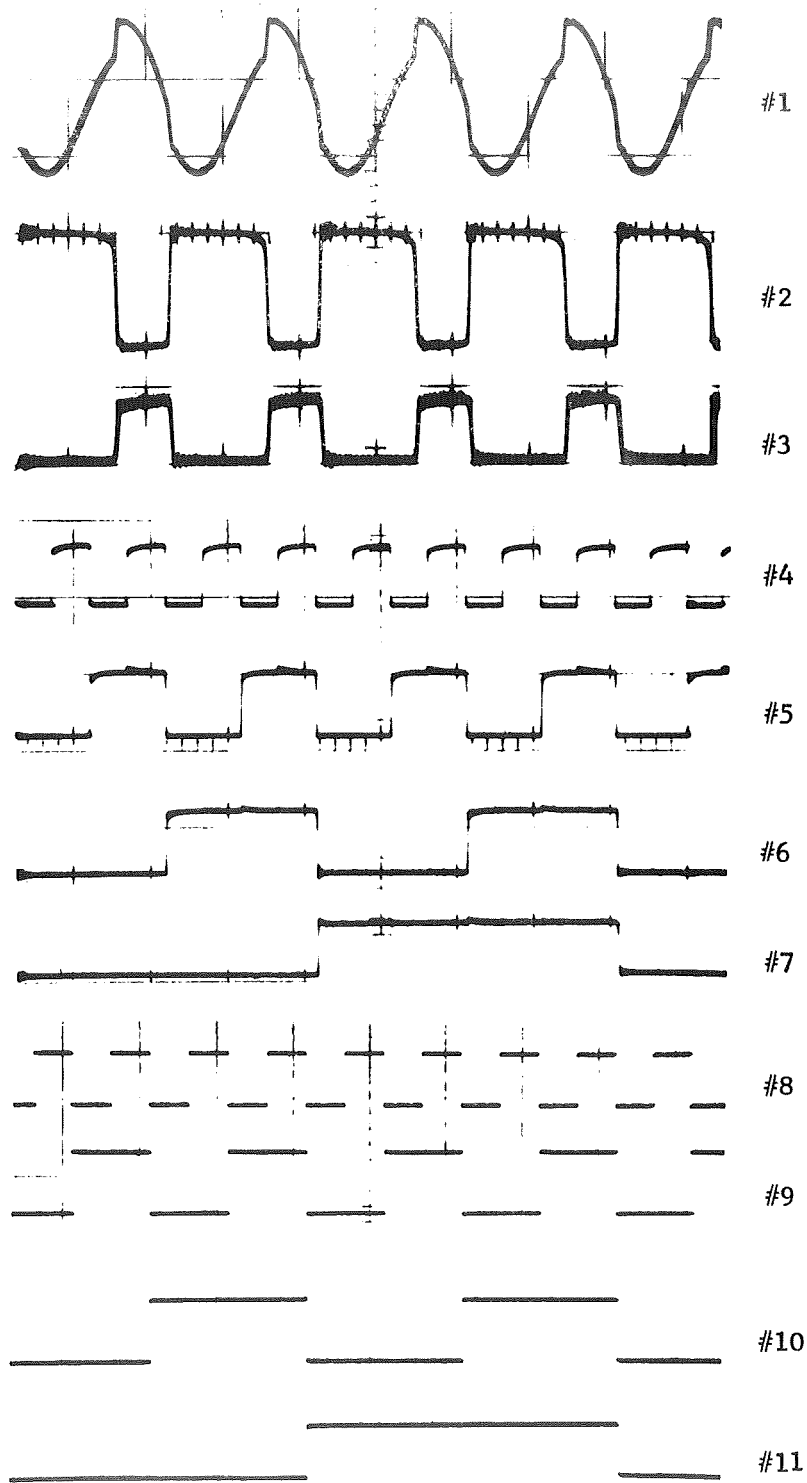


Figure 14. Logic unit waveforms.

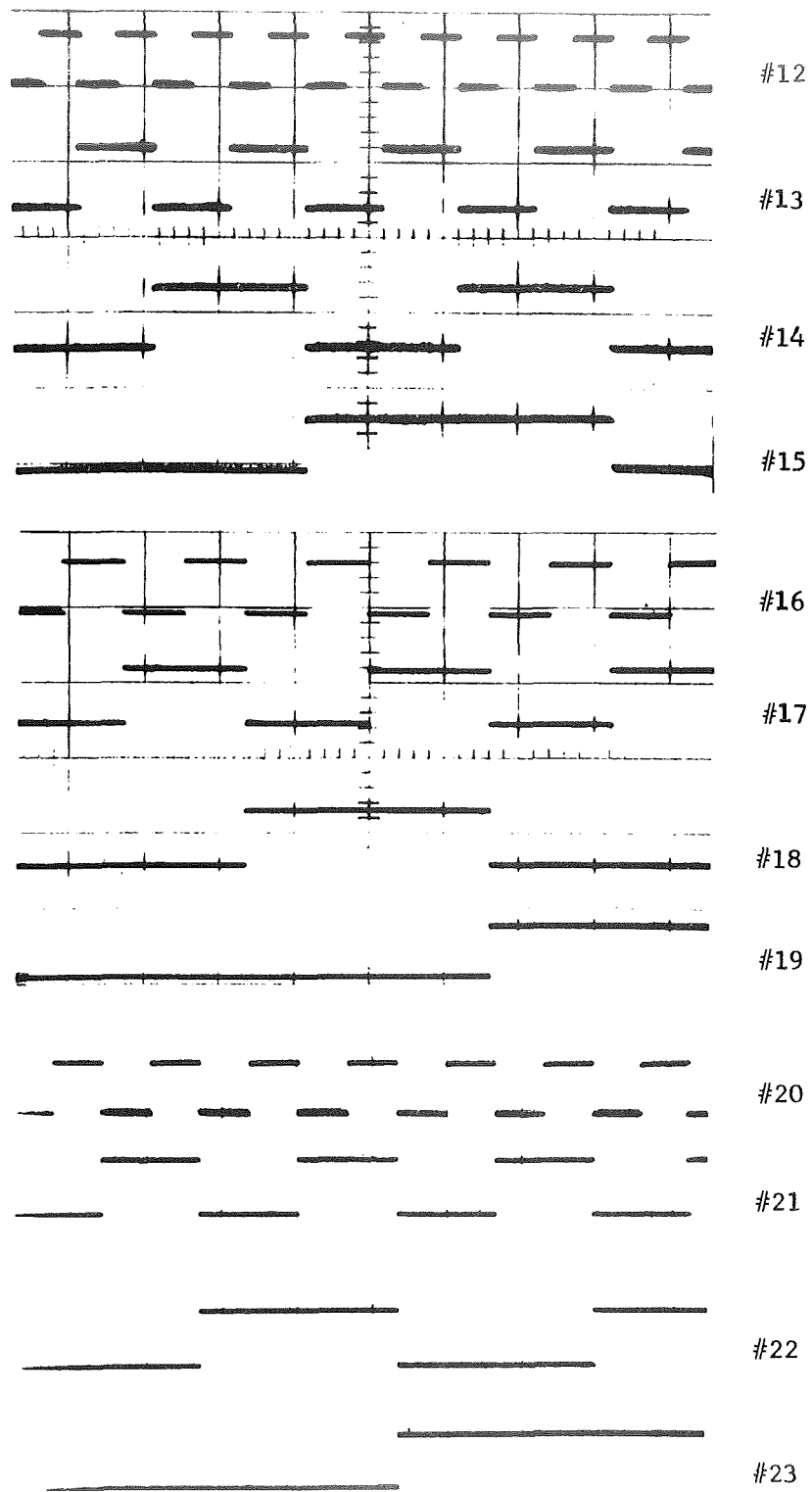


Figure 14. (Continued)

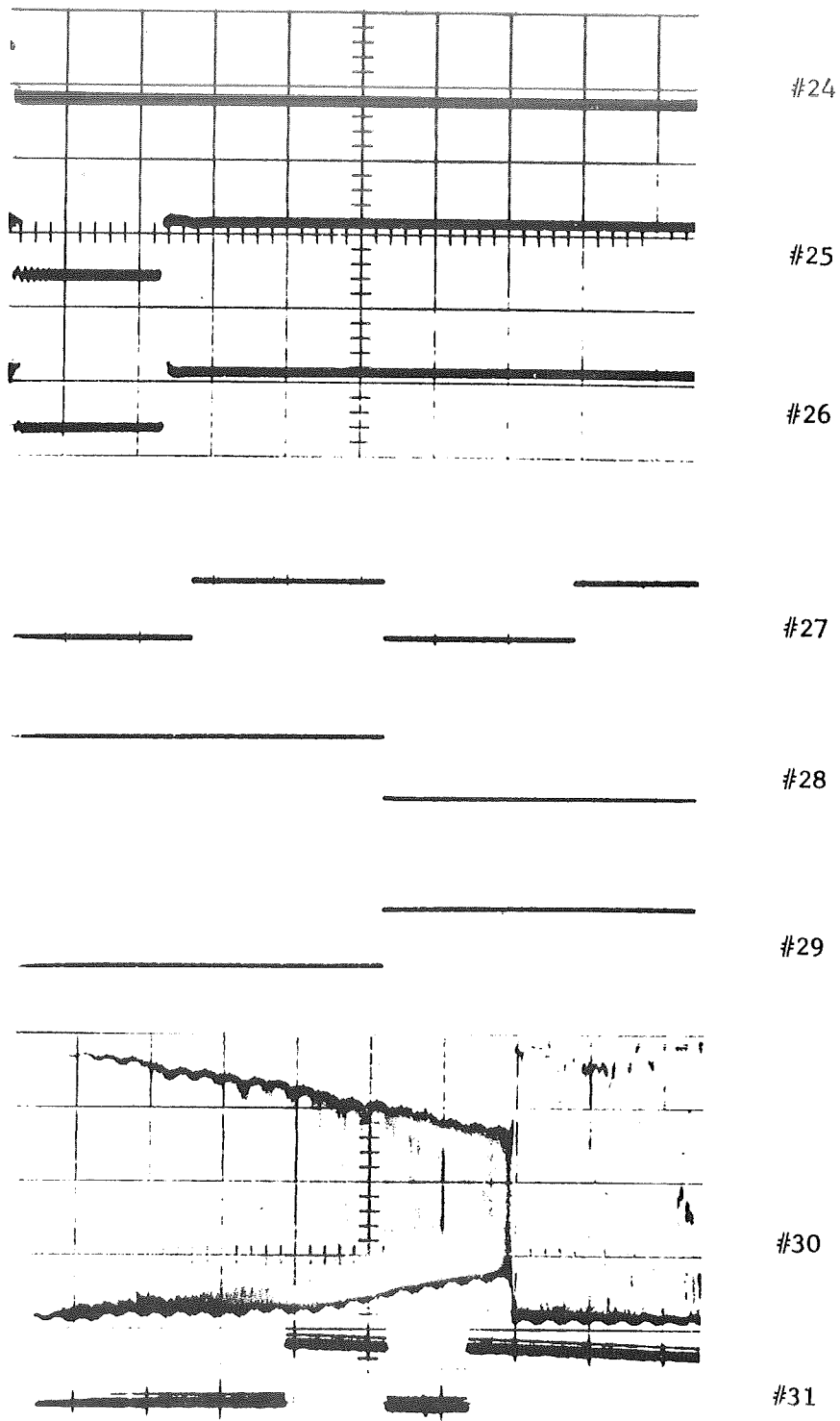


Figure 14. (Concluded).

ZERO CROSSING DETECTOR

The purpose of the zero crossing detector (ZCD) is to detect the time at which the input signal crosses zero volts. The ZCD used in the LAG is located on logic board 21 and provides a negative output pulse when the video crosses zero volts in the negative direction; this is 1 pulse per fringe. There are connections on the logic unit for using an external ZCD. This external ZCD is an EG&G T140/N which feeds the detected pulse through an EG&G DS104/N Scaler Driver. These units are described in the manufacturer's manuals. The following paragraphs describe only the ZCD on logic board 21. (Refer to the logic unit schematics in the Appendix.)

The video from the preamplifier is fed to the ZCD on pin 4 and through capacitor C3. Resistor R3 is adjusted so that tunnel diode TD1 fires just as the video crosses zero volts in the negative direction. When tunnel diode TD1 fires, transistor Q1 is turned on. Because of hysteresis, transistor Q1 conducts until the video input is approximately 0.5-volt positive and then cuts off. Thus, the video amplitude must be approximately 0.5-volt peak to "cock" the tunnel diode stage. Accuracy of data is partly dependent on how close to zero crossover tunnel diode TD1 fires. (Refer to the ZCD Alignment paragraph of this report.)

The remaining stages on logic board 21 are pulse amplifiers. The output at pin 6 is a negative-going pulse for each zero crossing in the negative direction. This output is essentially a square wave (0 to 5 volts) because the pulse width is determined by the video frequency.

FRINGE COUNTER

The fringe counter consists of 20 flip-flops on cards 23, 24, and 25, delay distance switches, measure distance switches, three 8-input NAND gates on card 26, and three 4-input NAND gates on card 27.

The delay distance switches set the fringe counter to a predetermined number when a reset pulse is received. The time taken to finish filling the counter is the delay time or the time elapsed between the end of the reset pulse and the beginning of the A-start pulse. All stages of the fringe counter flip over to a zero count on the first pulse after the counter is filled. The delay distance switches no longer affect the count unless another reset pulse is received.

The measure distance switches set a predetermined count in the counter. This preset count determines the portion of the drop distance to be measured. The measure distance precount is effective at all times, so the delay count must always be less than the measured time. When the counter is full the second time, another pulse is fed from the fringe counter to stop Counter A and start Counter B. The fringe counter then flips over to zero on the next input cycle of video. When the counter is full the third time, a pulse is gated out to stop Counter B and to start Counter C. The fringe counter fills again and a pulse is gated out to stop Counter C.

Both the delay and measure distance are measured in powers of 2. The delay distance is set as small as possible after the bird is in free-fall. The maximum measure distance of the LAG is 2^{19} fringes per measuring interval. (In the unequal measuring distance configuration, the total counting time consists of three measuring intervals.)

Each time the fringe counter fills, a pulse is produced. This pulse is gated to the proper time-interval counter by the state counter outputs.

STATE COUNTER

The state counter (Fig. 15) consists of three counter stages on card 23. The first stage is set to the full condition (high output), and the other two stages are cleared (low output) when a reset pulse is received. The state counter counts each pulse produced at pin 18 of card 27 (each time the fringe counter fills). Figure 16 shows the state counter output waveshapes at the respective test points.

Each "full count" pulse from the fringe counter is gated to the A-start output. The first A-start pulse after reset starts Counter A. This first pulse is not gated to the other outputs. When Counter A starts, the Counter A-start input "locks" and is not affected by any other pulses until the counter is reset. State 1 is the state in which only the A-start pulse can be gated through.

The lagging edge of the first fringe counter "full count" pulse causes the first stage of the state counter to switch to "low," which in turn switches the second stage to "high." The second stage output (TP-6) enables the A-stop NAND gate (state 2), and the next "full count" pulse is gated out to stop Counter A and start Counter B.

The lagging edge of the second "full count" pulse switches the first stage of the state counter back to "high." The first- and second-stage outputs are both "high," enabling the B-stop NAND gate. (This is state 3.) The third "full count" pulse is gated out to stop Counter B and start Counter C.

The lagging edge of the third "full count" pulse switches the first two stages to "low" and the third stage to "high," enabling the C-stop NAND gate. (This is state 4.) The next "full count" pulse is gated out to stop Counter C.

The state counters continue to change state and gate out start and stop pulses; however, only the first pulse (after reset) to any of the time interval counter start or stop inputs will affect that counter's input. Each start and stop input is "locked" with its first pulse and remains "locked" until the counter is reset.

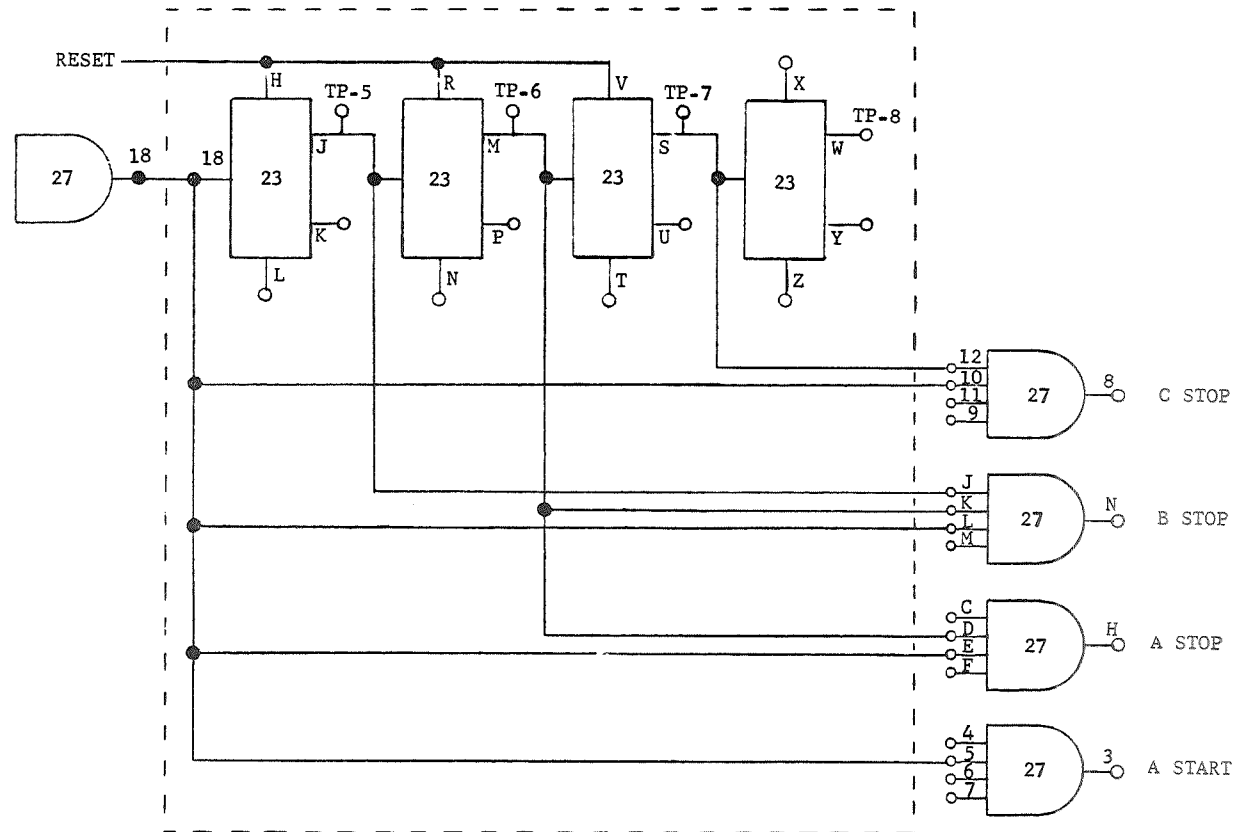


Figure 15. State counter.

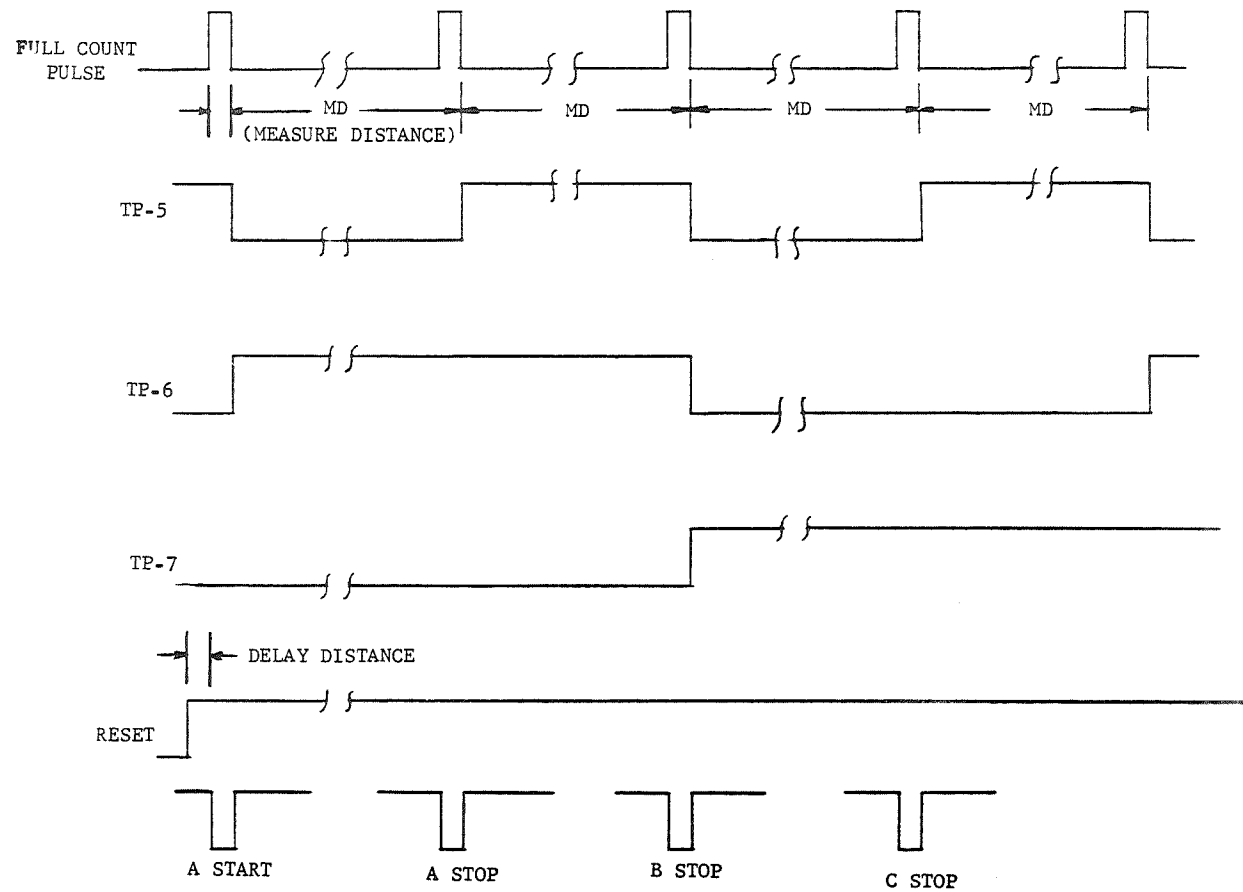


Figure 16. State counter waveshapes.

CABLE DRIVERS

The cable drivers consist of four drivers on cards 30 and 31 for the time interval counters and four drivers on card 32 for the system computer. The system computer contains its own time interval counters and is described in a separate manual. The output pulses to the computer are fed through an IC chip on card 30 to the cable drivers on card 32. Card 30 also contains a shaping circuit which accepts the system 1 MHz and provides a 1-MHz square wave output (clock). This clock output is not used at present. Cards 30 and 31 are interchangeable with respect to the time-interval counter outputs, but not with respect to the system computer nor the clock pulses. (Refer to output driver cards 30 and 31 schematics located in the Appendix.)

ALIGNMENT

Proper alignment of the LAG is required to ensure accurate measurement of gravity. The alignment procedures contained in this section should be performed whenever misalignment is observed because of repair or other disturbances of the LAG.

Table Alignment

TOP TABLE

The bird must be positioned directly over the Brewster window in the top chamber to prevent "walk" during a drop. The top table alignment is accomplished as follows:

1. Open top vacuum chamber and remove bird and Brewster window.
2. Insert the aperture plate in place of the Brewster window.
3. Drop the plumb bob through the hole in the plate and attach the string to the release finger so that the plumb bob hangs in the bottom chamber.
4. Cover the large port on the side of the bottom chamber to prevent air movement from moving the plumb bob.
5. Level the top table to ± 0.5 arc minute.
6. Turn the adjustment screws on the release mechanism until the string remains clear of the plate. If these adjustments do not move the mechanism far enough, set the adjustments so that the release mechanism is approximately centered in the chamber, and tilt the top table until the string clears the plate.

7. Record the top table tilt in both horizontal axes while the string is clear of the plate.

BOTTOM TABLE

Level the bottom table in both horizontal axes to ± 0.5 arc minute.

ALIGNMENT BETWEEN CHAMBERS

One or both of the tables may shift horizontally, causing a misalignment between the two chamber Brewster window openings. This can be checked visually by looking up through the bottom chamber with the beam splitter removed. This alignment becomes more important if Brewster windows are used in the bottom chamber ports. Alignment between chambers is accomplished as follows:

1. With both tables off air, check alignment of the chamber openings. The two tapered pins on the bottom table should force the tables into alignment. If the chamber openings are not in alignment with the tables off air, the top chamber will have to be shifted horizontally on the top table. This is done by loosening the bolts which hold the top table and sliding the top chamber to bring the two chambers into alignment. Tighten the bolts.

2. If the chambers are in alignment off air but out of alignment on air, one table will have to be shifted horizontally. The air pistons have some horizontal play which can move the tables out of alignment.

3. Remove the air pressure from the top table air piston.

4. Apply enough air to the bottom table so that the top table barely clears all four of its supports. Lower the tables.

5. Apply air pressure to both tables and raise them to their operating positions. The top table should be approximately 0.5 inch above its supports and the bottom table approximately 0.75 inch above its supports. Recheck alignment of the chamber openings.

6. If the openings are still out of alignment, repeat steps 3 through 5. If the openings are still out of alignment, raise the bottom table off its supports with a fork lift. Lower and repeat if necessary.

ZCD Alignment

The ZCD must provide an output negative pulse when the video signal crosses zero in the negative direction. The following alignment procedure covers logic board 21. For the EG&G ZCD alignment, see the manufacturer's manual.

1. Apply a 1-MHz signal through the test circuit (Fig. 17) to the logic video input.

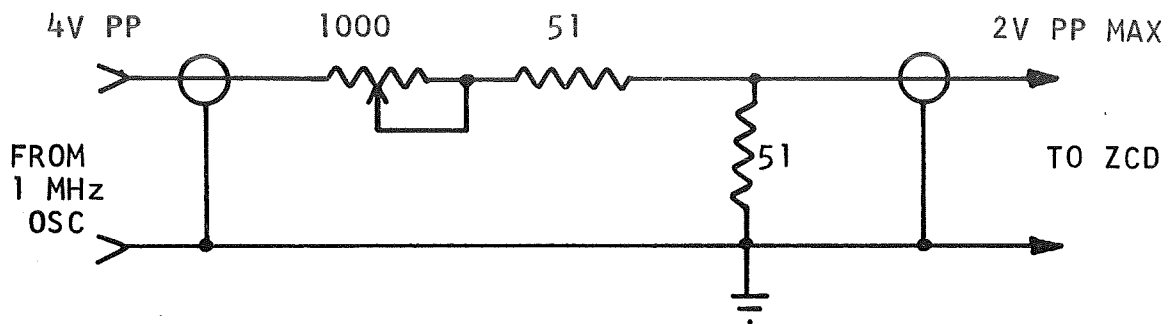


Figure 17. 1-MHz test circuit.

2. Trigger the oscilloscope externally from TP-1 of logic board 23.
3. Decrease the amplitude of the 1-MHz signal until the ZCD barely triggers (approximately 500 millivolts peak).
4. Using a dual-channel oscilloscope with a rise time of 5 nanoseconds or less, observe the 1-MHz signal input and the waveform at TP-5 of board 21.
5. Adjust the trimpot on board 21 until the waveform at TP-5 goes positive just as the 1-MHz signal crosses zero in the negative direction. The ZCD should trigger within ± 5 nanoseconds of zero crossing.
6. Increase the 1-MHz signal to 1-volt peak and observe zero crossing. Triggering should occur within ± 5 nanoseconds of zero crossing.

Optical Alignment

Following mechanical alignment of the LAG tables, an optical alignment is necessary to bring the bird and reference beams into coincidence and produce fringes, and to place the bird beam parallel to the gravitational vector. Optical alignment is accomplished in six steps consisting of:

1. Laser preparation.
2. Preliminary adjustments.
3. Alignment along gravity (\vec{g}).

4. Reference retroreflector alignment.
5. Maximization fringe visibility.
6. Positioning of the photomultiplier.

The LAG is aligned by what is called the “no-walk” method. Using this method, alignment of the bird laser beam parallel to \vec{g} is assured by observing that no lateral shift of the bird image occurs as the bird is released and falls. This method requires that no angular momentum or horizontal displacement be imparted to the bird by the release mechanism as the bird is released. If attempts to remove the bird-image walk by moving the laser beam are unsuccessful, it is likely that the top table is not properly leveled as determined by the plumb bob (see Item 7 under Top Table) and/or that the release mechanism is giving a “kick” to the bird as it is released. These difficulties must be removed before successful alignment can be achieved.

LASER PREPARATION

Instructions for turning on and adjusting the stabilized wavelength laser are found in the manufacturer’s manual. Instruction manuals are also available for the polarization rotator and beam-expanding telescope. Figure 18 shows the laser and its accessories.

The Spectra-Physics Model 310 polarization rotator is attached to the output end of the Perkin-Elmer Model 5800 laser by its standard optical threads. The first ring on the rotator near the thread is its locking ring. The second ring carries the polarization vernier and is locked in place with the vernier in an easily read position with an Allen wrench. The orientation of the polarization vector over a range of 4π radians is controlled by rotation of the third ring.

The steel adapter collar is slipped over the polarization rotator and screwed to the laser. The Spectra-Physics Model 332 spatial filter is attached to the collar by its threaded end and lock ring. The lock ring can be tightened with a special wrench. Use of the spatial filter aperture is optional. Spatial noise in the output beam is not usually a problem; therefore, the aperture and its attendant loss in output power is not usually needed. Refer to the Model 332 Instruction Manual for adjustment instructions. The collimating accessory lens mounts to the front of the spatial filter and should be adjusted to produce a collimated laser beam about 8 millimeters in diameter.

The laser assembly is complete and ready for mounting on the lower LAG table.

PRELIMINARY ADJUSTMENTS

Preliminary adjustments are made to place each optical element in the center of its adjustment range. (Refer to Fig. 19 for placement of the optical elements.)

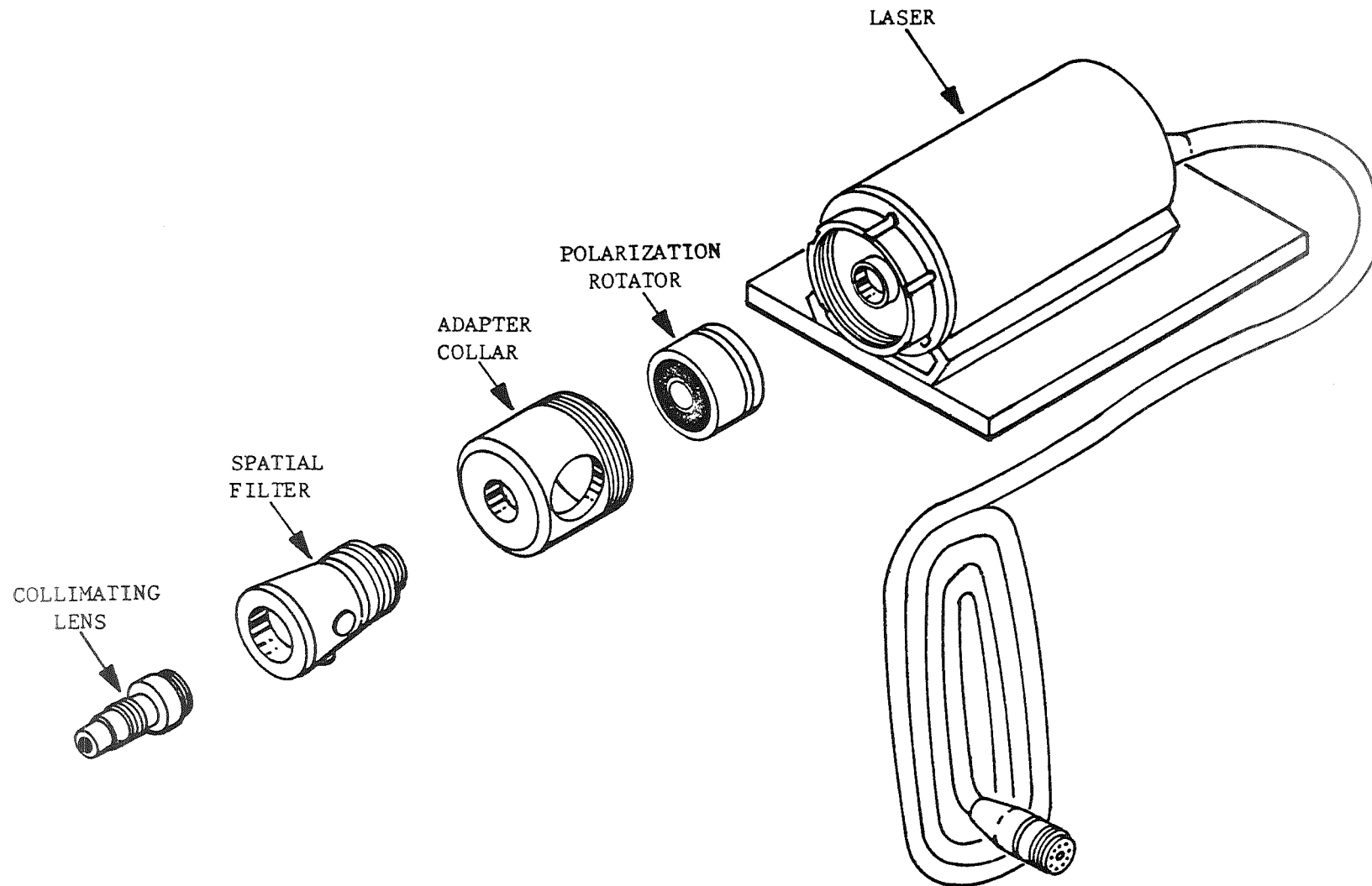


Figure 18. Laser and accessories.

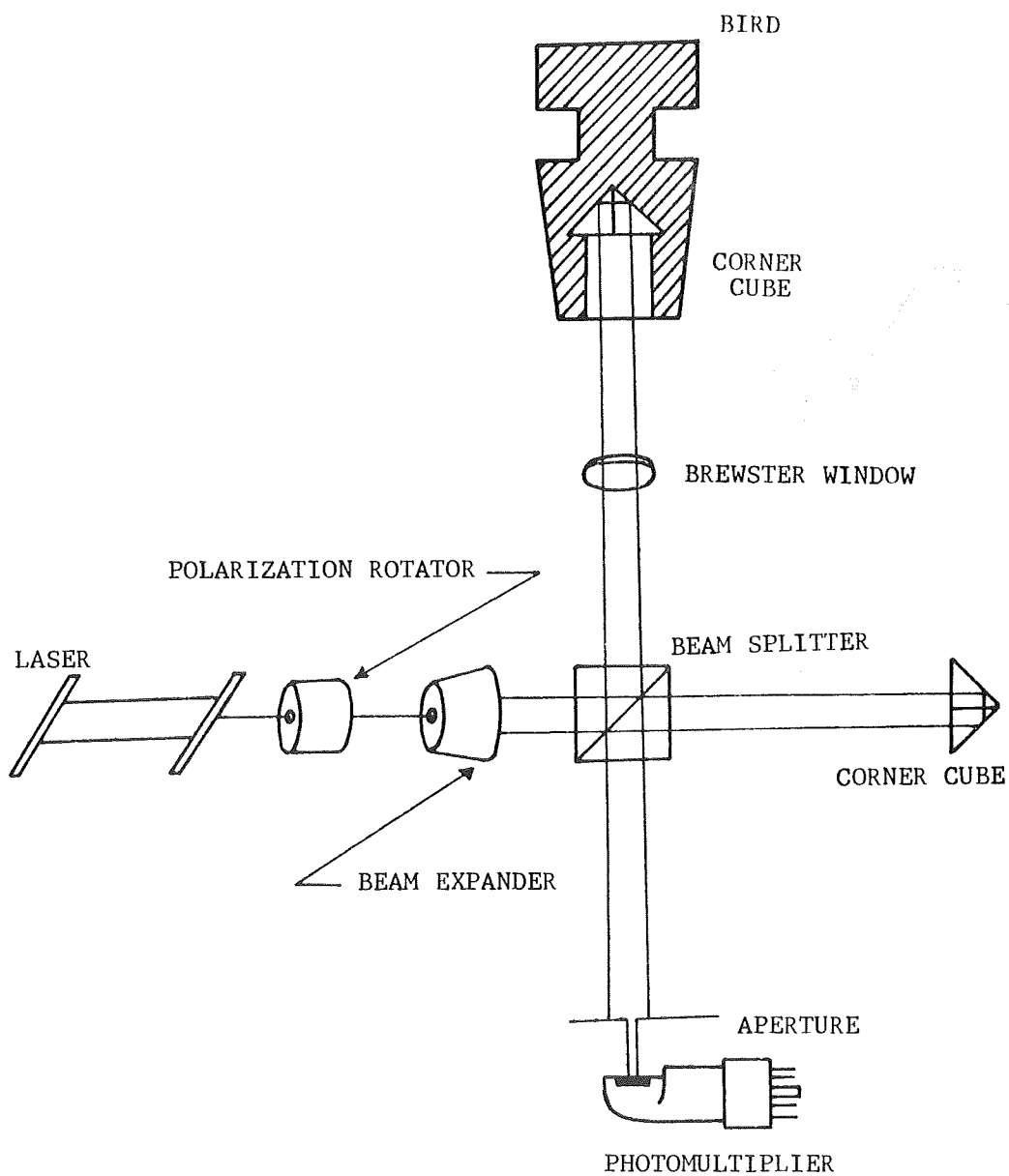


Figure 19. Arrangement of optical components.

Place the beam splitter on the beam splitter table. Center the traverse adjustments on the beam splitter table and bring the beam splitter to an approximate level by a rotation of the table tilt screws.

Center the reference retroreflector assembly with its traverse screws.

Mount the laser assembly to its adjustment rack. By a combination of shimming and tilting the laser, raise it until its beam is approximately parallel to the bottom table and at the height of the beam splitter and reference cube. Swing the laser about its vertical axis by adjusting the differential screw and traverse the laser horizontally until its beam intersects the center of the beam splitter and the reference cube. After loosening the beam splitter base attachment screws, rotate the beam splitter base until the beam reflected from the first surface of the beam splitter is incident back on the laser. Carefully tighten the base screws. This adjustment ensures that the beam splitter horizontal tilt axes are parallel and perpendicular to the incident laser beam, respectively.

Place the aperture plate used in plumbing the drop column under the Brewster window opening in the lower chamber. The mechanical alignment with the plumb bob has defined a gravity reference in the drop chamber to be a line drawn from the center of this aperture plate to the center of the release finger. If the laser beam is simultaneously centered on this plate and the release finger, a rough initial alignment will be achieved. Traverses and tilts of the beam splitter are usually sufficient to accomplish this alignment; however, a slight traverse and/or tilt of the laser assembly may be necessary.

ALIGNMENT ALONG GRAVITY

To prevent walk of the bird image during a measurement, it is necessary that the sensing laser beam be aligned parallel to the local gravity vector. Otherwise, the bird, which falls along \vec{g} , and the beam, which is not parallel to \vec{g} , will not be concentric at some portion of the drop, and image walk will result. If any LAG data are in this nonparallel condition, the acceleration measured is $\vec{g} \cos \theta$, where θ is the angle between \vec{g} and the laser beam.

When the aperture plate is removed after preliminary adjustments, and the photomultiplier is removed, the bird image should be visible on the ground beneath the LAG with the bird in its up position. If the preliminary adjustments have not been properly made, some search for the bird image may be required. (This search is easier if it is first done with the bird down, resting in its catcher.) As the bird falls, its image will be observed to shift laterally. By a series of fine adjustments to the beam splitter tilt screws and traverse motions, and to the laser tilt and traverse motions, the amount of bird image walk can be reduced to nil by trial and error on successive drops. The bird image should be round with the retro-reflector ray pattern centered on the image.

If the setting of the beam splitter and laser which eliminates image walk cannot be found, it is likely that the top table and drop column are not aligned along \vec{g} directly above the Brewster window opening, or that the bird release is giving some initial momentum to the bird at the instant of release. Both of these conditions must be eliminated to allow the "no-walk" method of alignment to work.

REFERENCE RETROREFLECTOR ALIGNMENT

When a setting of the laser and beam splitter which produces "no-walk" has been found, the reference retroreflector should be flipped into place and its image made to coincide with the bird image with the bird hanging from its release mechanism. The ray pattern rotation of the bird image is fixed by mechanical assembly, but the reference ray pattern can be changed by a rotation of the entire reference tube.

When the two images are coincident, circular fringes should appear in the common image. As one of the tables is slightly displaced vertically, these fringes will appear to grow from or shrink into the center of the pattern.

MAXIMIZATION OF FRINGE VISIBILITY

Maximum fringe visibility results when the reference and bird beams are of equal intensity. An adjustment of the polarization rotator is available to equalize the intensities. This adjustment is accomplished by comparing the visual intensities of the two images, or by comparing the photon noise produced by each beam in the photomultiplier. Rotate the polarization rotator to a position which equalizes the two beams.

POSITIONING OF THE PHOTOMULTIPLIER

An aperture should be selected for the photomultiplier that is slightly smaller than the width of the dark portion of a fringe. When the aperture is placed over the photocathode, the photomultiplier can be inserted beneath the lower table to a position where the images and fringe pattern fall on the aperture. Observing the fringe pattern on the face of the photomultiplier from beneath the lower chamber will confirm photomultiplier placement. A position of the aperture in the fringe pattern should be found which results in a strong video signal during a drop. Placement of the aperture on one of the radial lines in the image should be avoided; otherwise, a low video signal will result.

Bird Retrieval Mechanism Alignment

The bird retrieval mechanism performs the functions of catching the bird after free-fall, carrying it to the top of the drop chamber, cocking the bird-release mechanism, and returning the catcher to the bottom of the chamber. A long screw shaft extending the length of the drop chamber and a recirculating ball nut in the catcher raises and lowers the catcher

as the screw shaft is turned by an electric motor. Switches and relays in the bird-control unit govern the motor direction. (See the Motor Control Unit paragraph of this report.) A multiturn potentiometer geared to the screw shaft determines the speed of the motor; the catcher is slowed to a crawl at the upper and lower extremes of its motion.

Three critical adjustments must be made to the bird-retrieval mechanism to enable it to operate correctly. The speed-control potentiometer (cosine potentiometer R21) must be set in relation to the catcher position in the drop chamber. Two microswitches, S2 and S3, which reverse the motor direction at the top and at the bottom of the chamber and shut off the motor at the bottom must also be critically placed in relation to the lead screw.

The cosine potentiometer adjustment is easily made by slipping the timing belt past the cosine potentiometer gear. The adjustment is made so that the motor reaches its maximum speed in the middle of the drop chamber. When the catcher is at the ends of the chamber, the motor speed should be slow enough that the catcher is not jammed against the release mechanism at the top or the Brewster window at the bottom; however there should be sufficient torque in the motor to carry the catcher to the points where the microswitches are activated.

A nylon cam on the rotating disc which tracks the screw shaft activates the microswitches. The switch (S2) which stops the catcher at the bottom of the chamber should be set so that it is tripped when the catcher is about 3 centimeters (two turns of the lead screw) above the Brewster window. The position of the nylon washer on the rotating disc, the angular position of the arm which holds switch S2, and the thickness of the shims beneath switch S2 determine the position where the motor stops. The catcher should not be allowed to ride down to the bottom of the lead screw and interfere with the Brewster window because damage to the catcher could result. Coarse adjustments are made by shimming beneath switch S2 or by turning the lead screw and slipping the timing belt past the rotating disc (cam) drive gear. Finer adjustments can be made by changing the position of switch S2 around the camshaft.

Microswitch S3, which determines the point where the motor reverses direction, is also adjusted by means of shims and its angular rotation. It should be set so that the release mechanism is fully cocked by the bird when the catcher is up and that the recoil springs in the catcher are slightly compressed. The force with which the release mechanism is cocked determines the time required to release the bird. This force is governed by the point at which the motor direction is reversed. If the catcher rides up too high, the bird may be jammed in the catcher, making the opening of the vacuum chamber necessary. To prevent this and damage to the release mechanism or bird, initial adjustments of switches S2 and S3 should be made while hand turning the screw shaft. The mechanism can also be motor driven and stopped at any point by the stop-go switch.

MAINTENANCE

This section contains preventive maintenance information for the LAG.

Care and Protection of Optical Surfaces

The most common sources of contamination of optical surfaces are:

1. Smoke and oil in the atmosphere.
2. Fingerprints.
3. Oil from skin that may be dissolved in lens cleaning solutions.
4. Dust particles.
5. Moisture and saliva stains.
6. Corrosive atmospheres.

Some general precautions to be observed in handling optical components are:

1. Wear cloth or plastic gloves or finger shields.
2. Wash hands thoroughly before handling optical instruments.
3. Avoid unnecessary exposure of optical components to contaminating atmospheres.
4. Employ only recommended cleaning procedures.

Optical glass is softer than normal glass and is easily scratched. Components are usually coated in some way by various special-purpose coatings such as antireflection coating, interference filter coatings, etc. Although these coatings are reasonably durable, cleaning unavoidably degrades coating characteristics. Therefore, optical surfaces should be cleaned only when contamination is in evidence, such as:

1. Dust particles, fingerprints, or streaks made visible by light scattered from a light beam at the surface of the element.
2. Reduced transmission or reflection because of increased surface scatter or absorption of the incident beam.

If it has been determined by testing a sample or by consulting the manufacturer that cleaning the optical element will not harm it, the recommended cleaning procedure is:

1. Wash hands several times to ensure that excess skin oils are removed. Put on clean cloth or plastic gloves or finger shields.
2. Hold the component without touching the optical surfaces, and with a clean, compressed air syringe, draw all particulate matter from the contaminated surface by allowing the syringe to decompress naturally.
3. Carefully examine the optical surface for any other signs of contamination. If particles are visible, apply one or two drops of lens cleaner to the surface and rotate the optical surface in an attempt to wash off the contaminating particle. If the particle does not wash off, apply more lens cleaner and dislodge it with a clean cotton swab.

NOTE

Acceptable lens cleaners are spectroscopic or reagent grade acetone or methyl alcohol.

4. Apply one drop of lens cleaner to the surface and move the optical component so that the surface is wetted.
5. Touch the top of a swab to the coated surface, allow about 1 second for cleaner to be absorbed by the swab, and wipe once in one direction using light pressure. Use only enough pressure to maintain even contact across the surface while wiping.

NOTE

An alternative to the clean cotton swab is a folded square of lens tissue (genuine lens paper, not Sight-Savers) held by forceps or a hemostat. Folding should be done with forceps instead of fingers to avoid contamination of the paper.

NOTE

The swab can be wetted with cleaner and applied to the surface. Wet the swab thoroughly and shake off the excess, letting the excess carry off any oils present in the swab.

6. Immediately after wiping, examine the optical surface for streaks or other contaminants. The presence of streaks indicates that full contact was not maintained across the surface. The presence of scratches on coated surfaces indicates that either too much pressure was used or that all particulate matter was not removed prior to wiping.

7. Discard the swab after use. Never reuse a swab.

8. If the surface was not wiped dry in step 5., air drying will leave residue on the surface; therefore, if streaks are observed on the surface in 6., repeat steps 4. through 7.

Electronic Systems

The electronic systems require little preventive maintenance. Most of the preventive maintenance is covered in the Alignment and Operation Sections of this report. In addition, supply voltages in the equipment should be checked with a good VTVM about once a month, and more often if the voltages tend to drift. These voltages should be adjusted according to manufacturers' specifications. The time base oscillator, time interval counters, and oscilloscopes should be sent to the calibration facility according to their schedules. Malfunctions can be traced and repaired with the help of the manufacturers' manuals and the theory contained in this manual.

Vibration Isolation System

The two filters in the vibration isolation system should be cleaned as needed. When the N₂ bottles pressures approach the system pressure, the bottles should be refilled. A bottle of N₂ should last several weeks. The tables should not be moved excessively while on air. If heavy objects must be placed on the tables or if it is necessary to stand on one of the tables, the pressure should be lowered so that the tables are supported by the legs and not by the air pistons.

Vacuum System

The oil level in the rotary roughing pump should be checked about once a week and oil replaced as needed. The water cooling system should be checked daily to assure that there is enough water and flow rate to cool the ion pump. A vacuum of at least 10⁻³ torr should be maintained in the vacuum chamber except when opening the chamber.

Overall System Care and Protection

Near normal room temperature should be maintained. Extreme temperature changes may cause the optics to become misaligned and may also cause a leak in the Brewster

window. Care should be taken to prevent waterline leaks, which would wet the equipment. The hardware in the LAG shed, which is highly susceptible to rust, should be coated with oil to prevent rust. The optics should be kept dry to prevent condensation.

APPENDIX

DRAWINGS AND DIAGRAMS

Figures A-1 through A-19 are intended to supplement the other sections of this manual and will prove useful when troubleshooting and maintenance of the system is required.

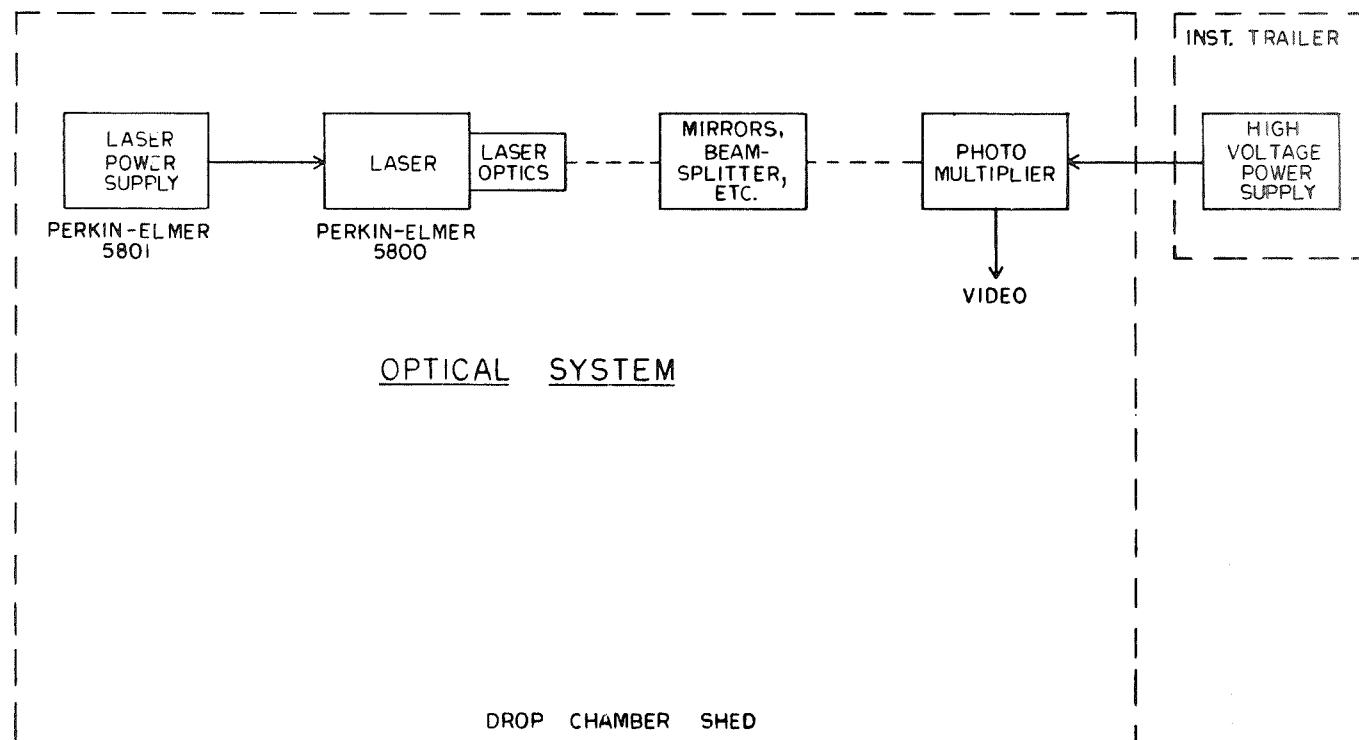


Figure A-1. Optical system block diagram – Laser Absolute Gravimeter (Mark II).

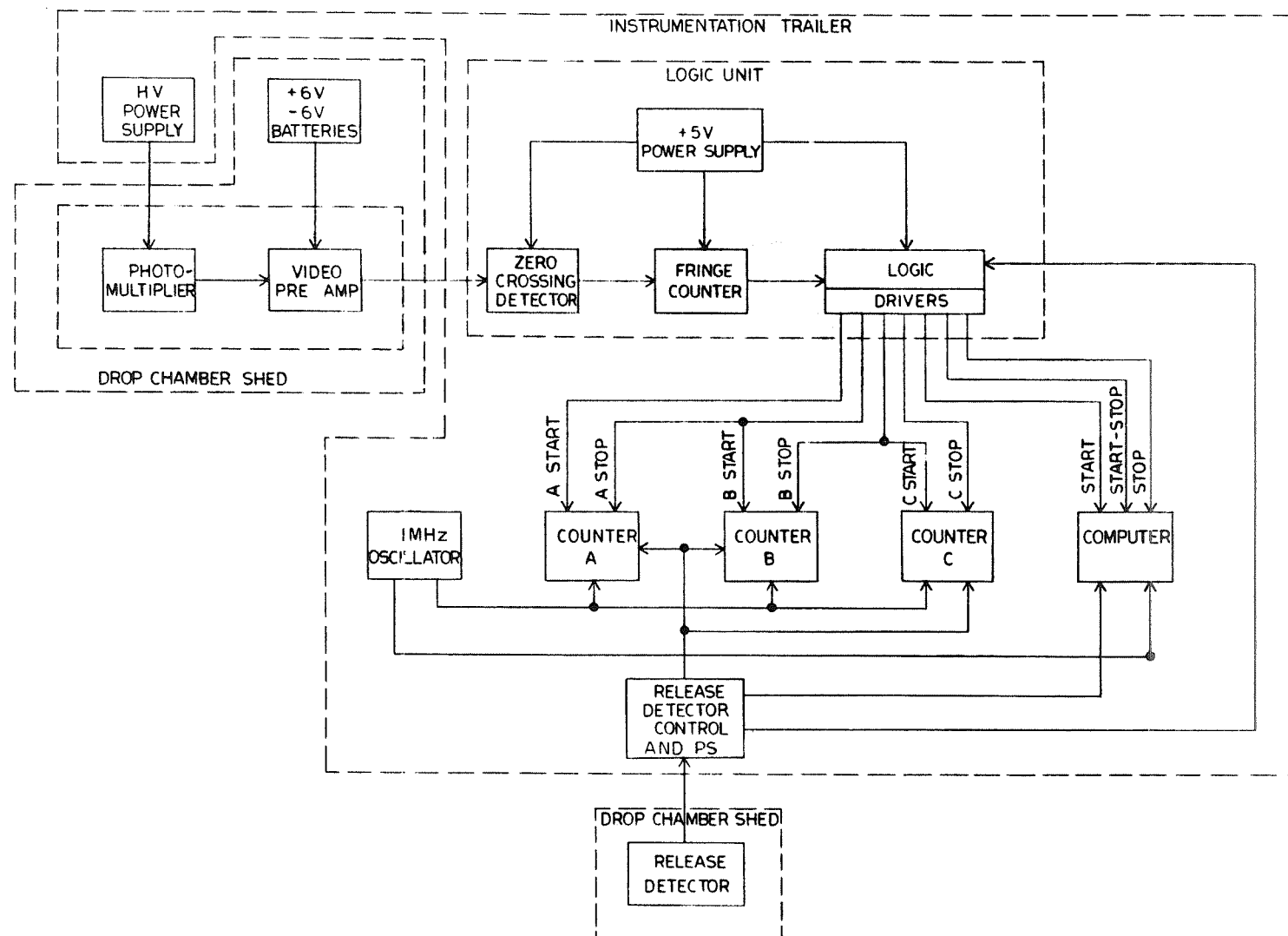


Figure A-2. Video and counting system block diagram – Laser Absolute Gravimeter (Mark II).

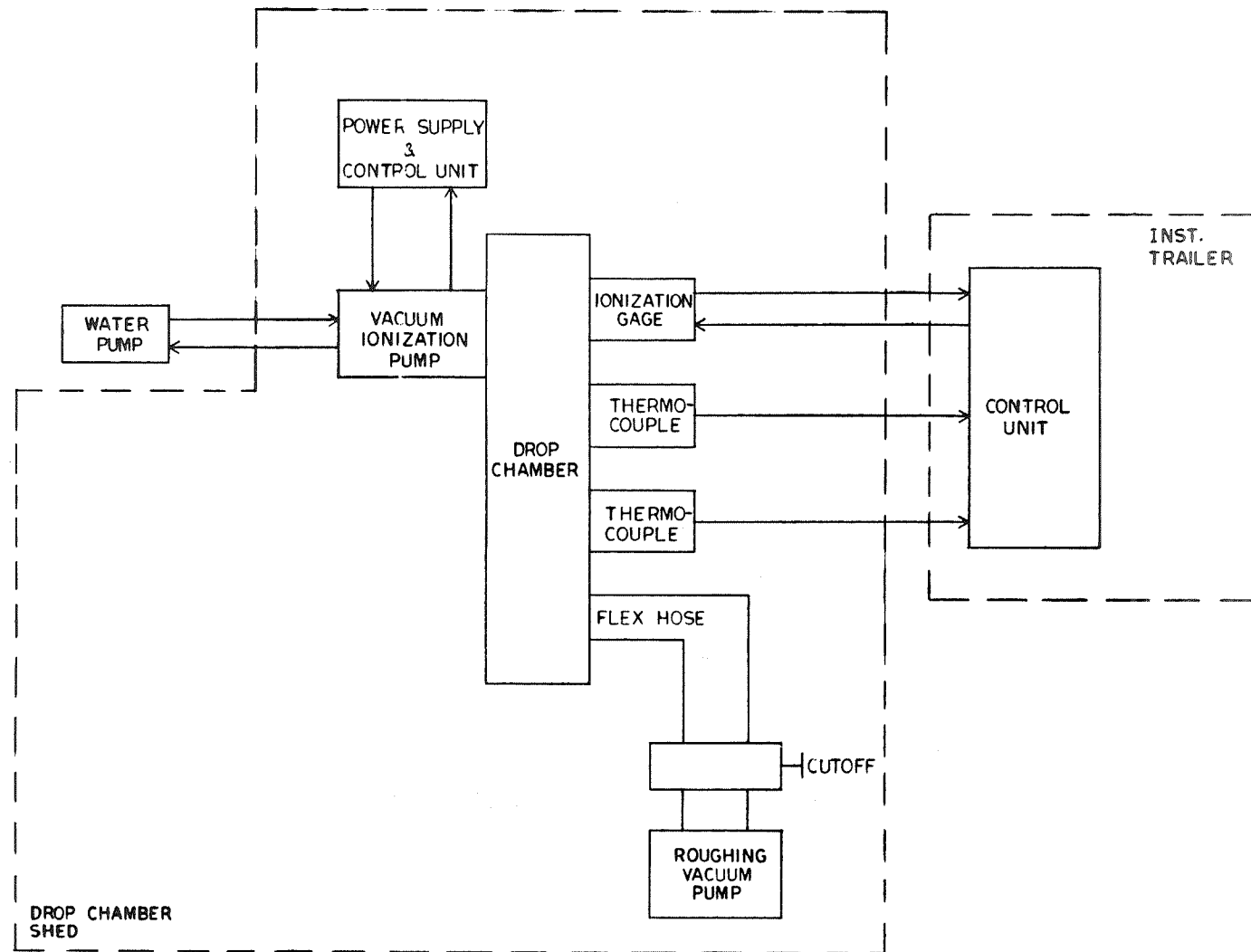


Figure A-3. Vacuum system block diagram – Laser Absolute Gravimeter (Mark II).

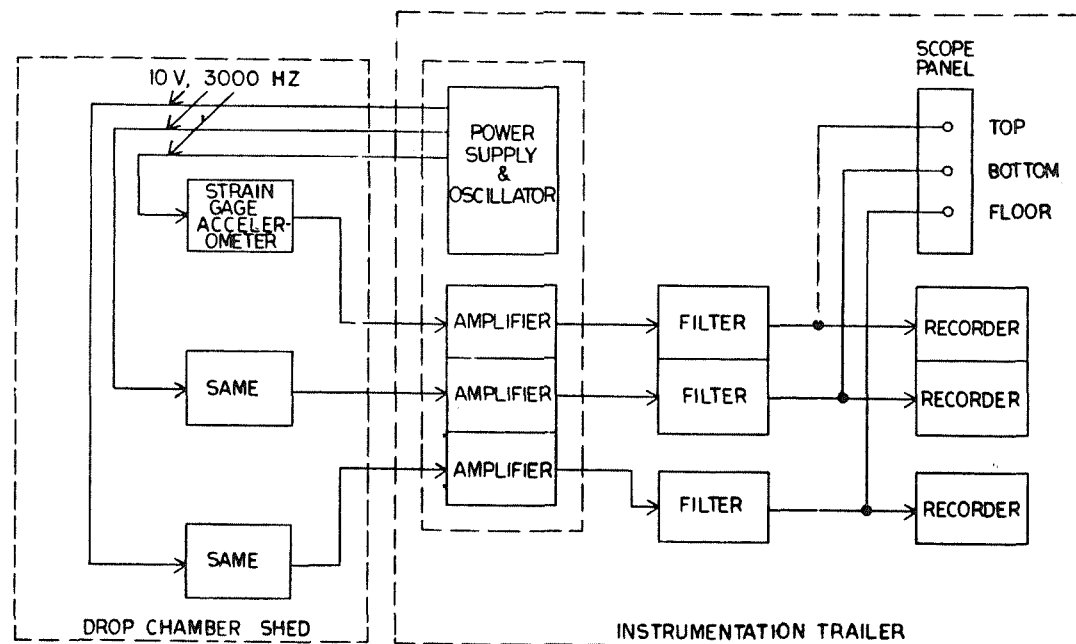
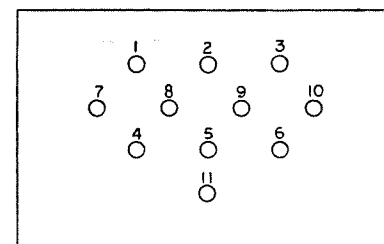


Figure A-4. Vibration measuring system block diagram – Laser Absolute Gravimeter (Mark II).

PART NO.	MP	REVISIONS				
		ZONE	SYM	DESCRIPTION	DATE	APPROVAL



INSTRUMENTATION TRAILER INTERNAL AND
EXTERNAL J-BOX

1. VIDEO
2. HIGH VOLTAGE (PHOTOMULTIPLIER)
3. HIGH VOLTAGE (IONIZATION) GAUGE
4. VACUUM THERMOCOUPLE # 1
5. VACUUM THERMOCOUPLE # 2
6. REMOTE BIRD CONTROL
7. FILAMENT VOLTAGE (IONIZATION GAUGE)
8. TRANSDUCER (TOP TABLE)
9. TRANSDUCER (EARTH VIBRATIONS)
10. TRANSDUCER (BOTTOM TABLE)
11. BIRD CONTROL

		UNLESS OTHERWISE SPECIFIED		ORIGINAL DATE OF DRAWING: JUL 30 1970		CABLE DIAGRAM		GEORGE C. MARSHALL SPACE FLIGHT CENTER	
SEE ENGINEERING RECORDS		DIMENSIONS ARE IN INCHES		CHECKED: [initials]		INSTRUMENTATION TRAILER TO DROP CHAMBER SHED LASER ABSOLUTE GRAVIMETER (MARK II)		NATIONAL AERONAUTICS AND SPACE ADMINISTRATION HUNTSVILLE, ALABAMA	
		TOLERANCES ON FRACTIONS		DESIGNED: [initials]					
		DECIMALS		APPROVED: [initials]					
		MATERIAL		SUBMITTED					
		HEAT TREATMENT		APPROVED					
NEXT ASSY USED ON		FINAL PROTECTIVE FINISH		DIRECTION		WEIGHT CHECKER DATE CODE 14281		SK220-670	
APPLICATION						SCALE NONE UNIT WEIGHT		SHEET OF	

Figure A-5. Cable diagram instrumentation trailer to drop chamber shed – Laser Absolute Gravimeter (Mark II):

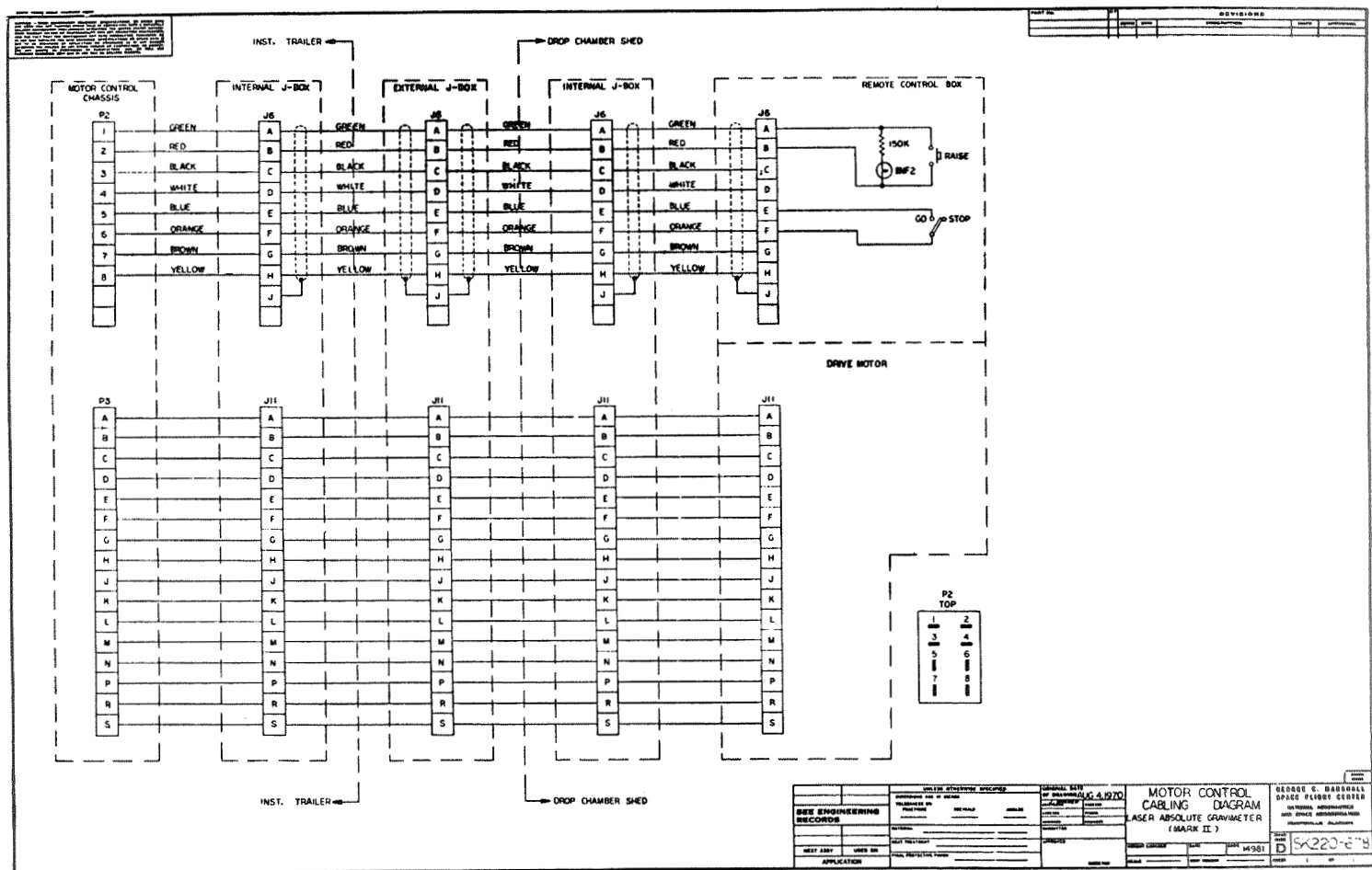


Figure A-6. Motor control cabling diagram – Laser Absolute Gravimeter (Mark II).

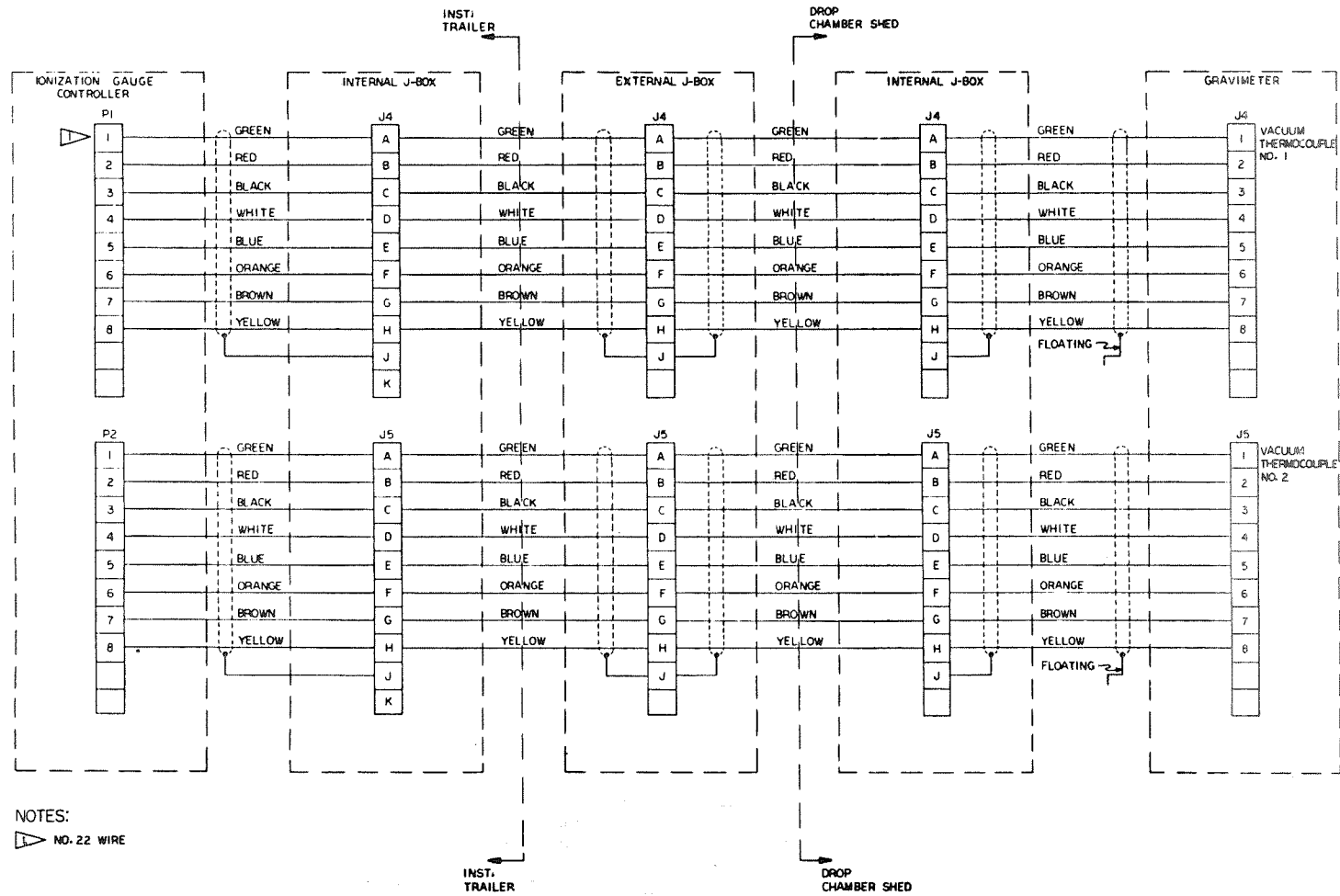


Figure A-7. Thermocouple cabling diagram – Laser Absolute Gravimeter (Mark II).

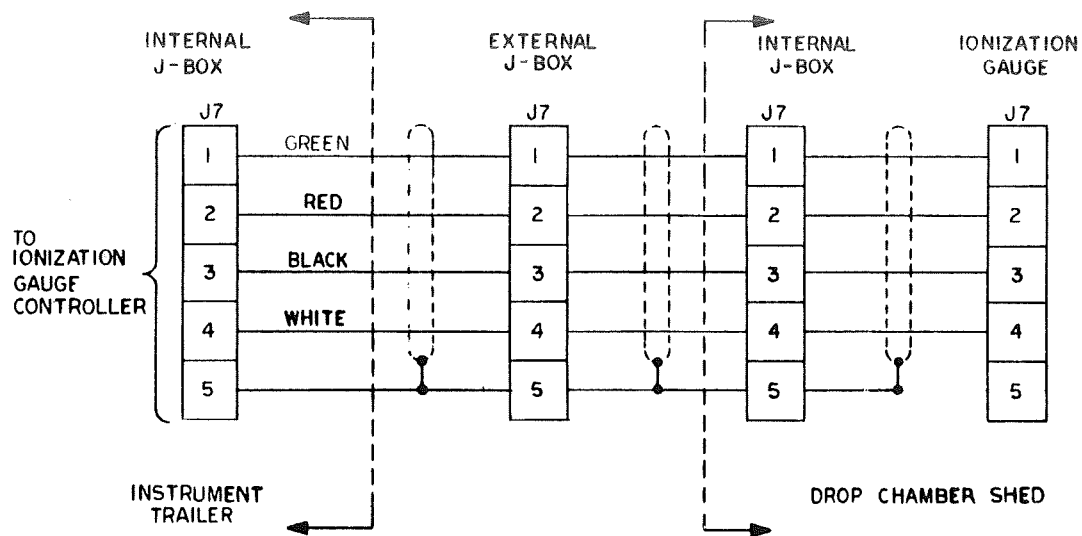


Figure A-8. Ionization gauge filament cabling diagram —
Laser Absolute Gravimeter (Mark II).

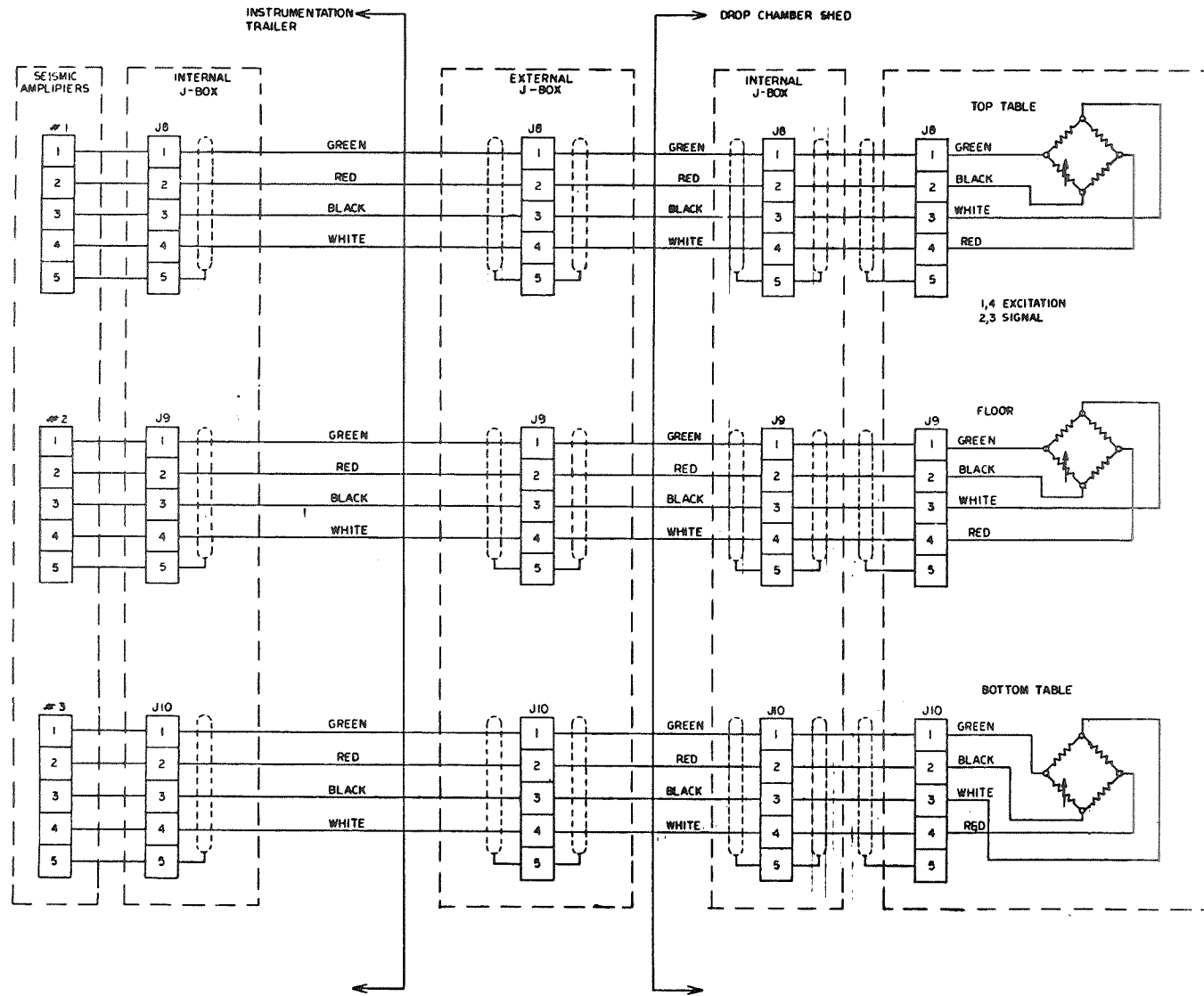


Figure A-9. Vibration measuring system cabling diagram — Laser Absolute Gravimeter (Mark II).

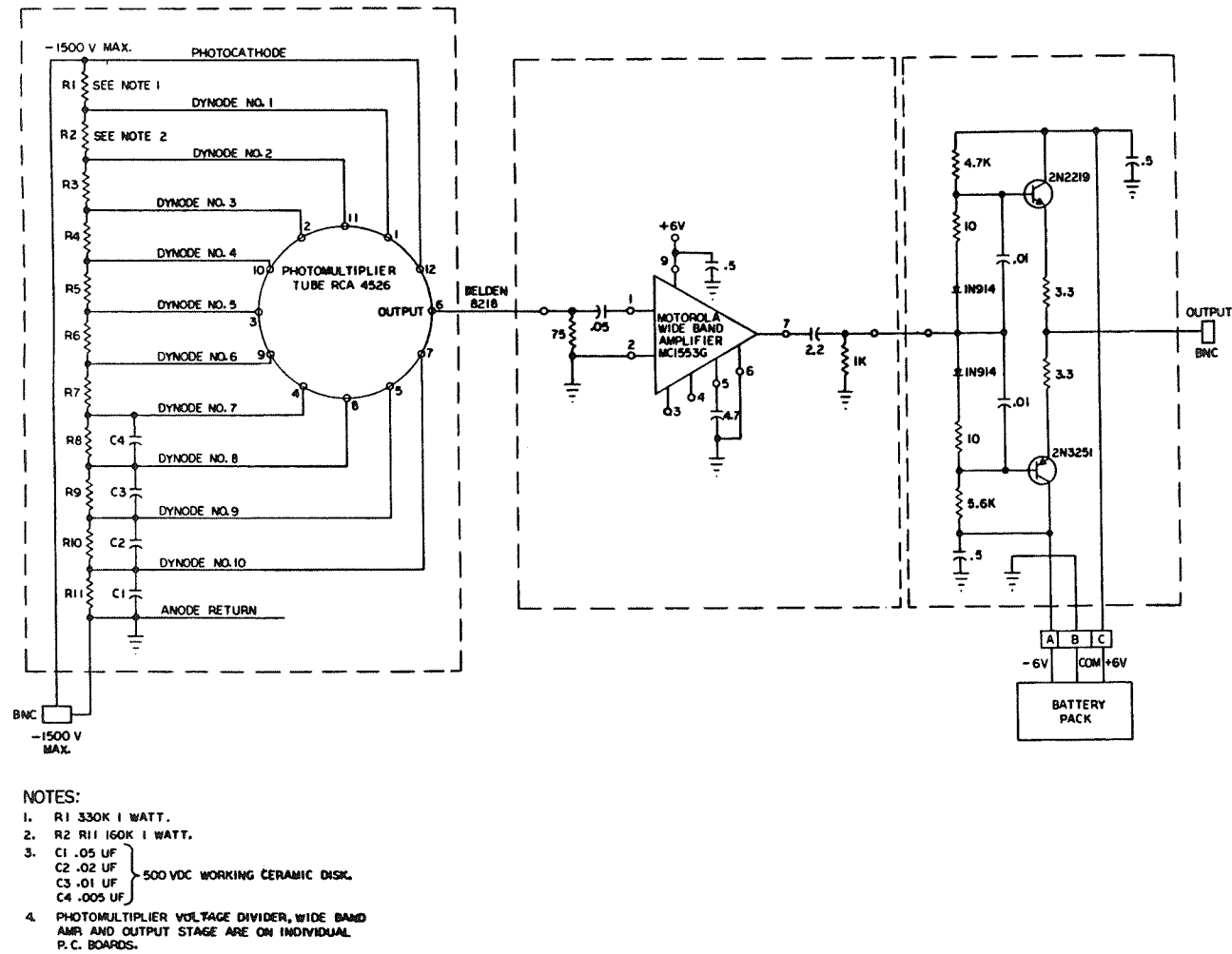


Figure A-10. Photomultiplier detector and video preamp – Laser Absolute Gravimeter (Mark II).

SK220-67

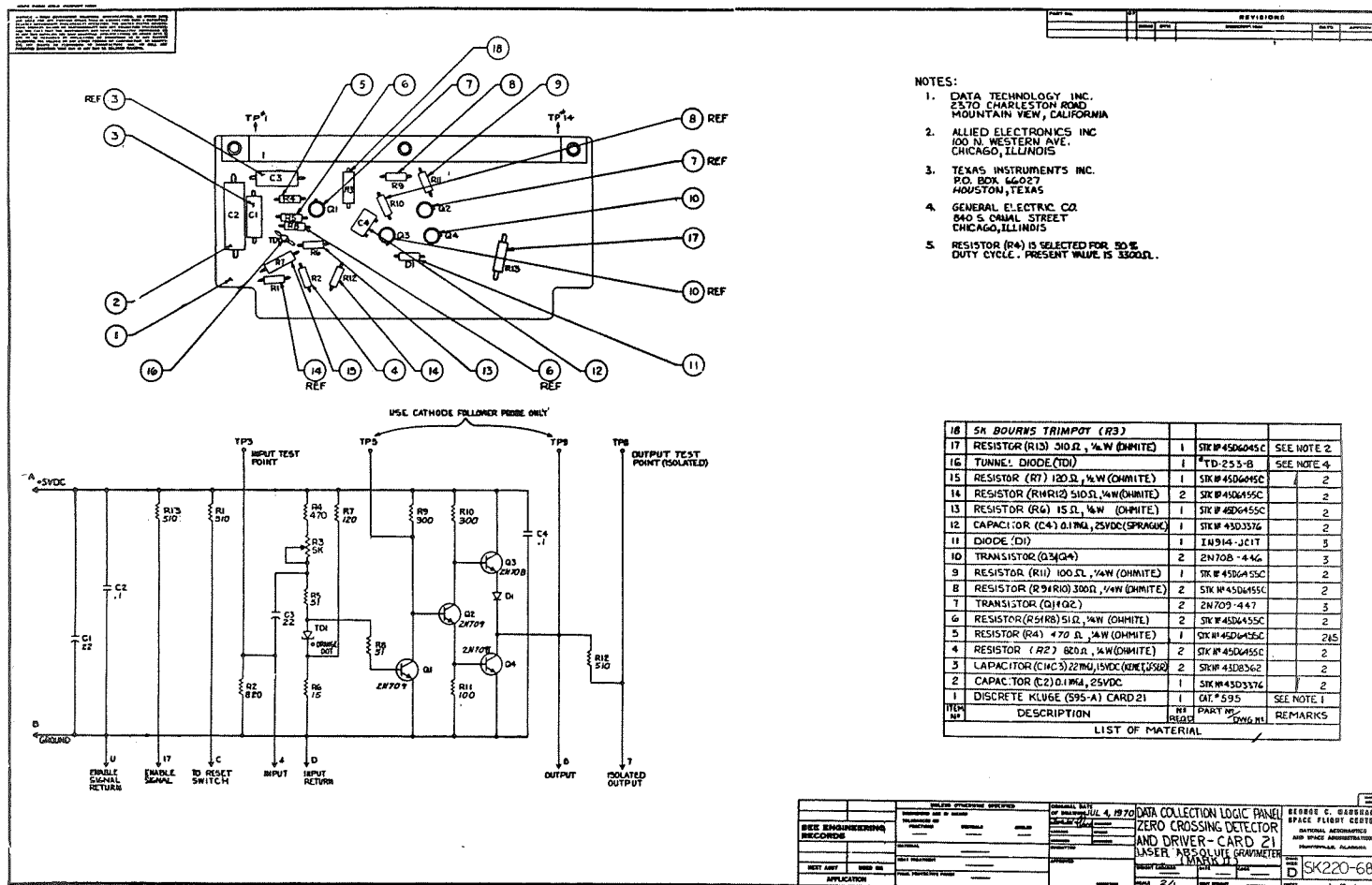


Figure A-12. Data collection logic panel zero crossing detector and driver-card 21 – Laser Absolute Gravimeter (Mark II).

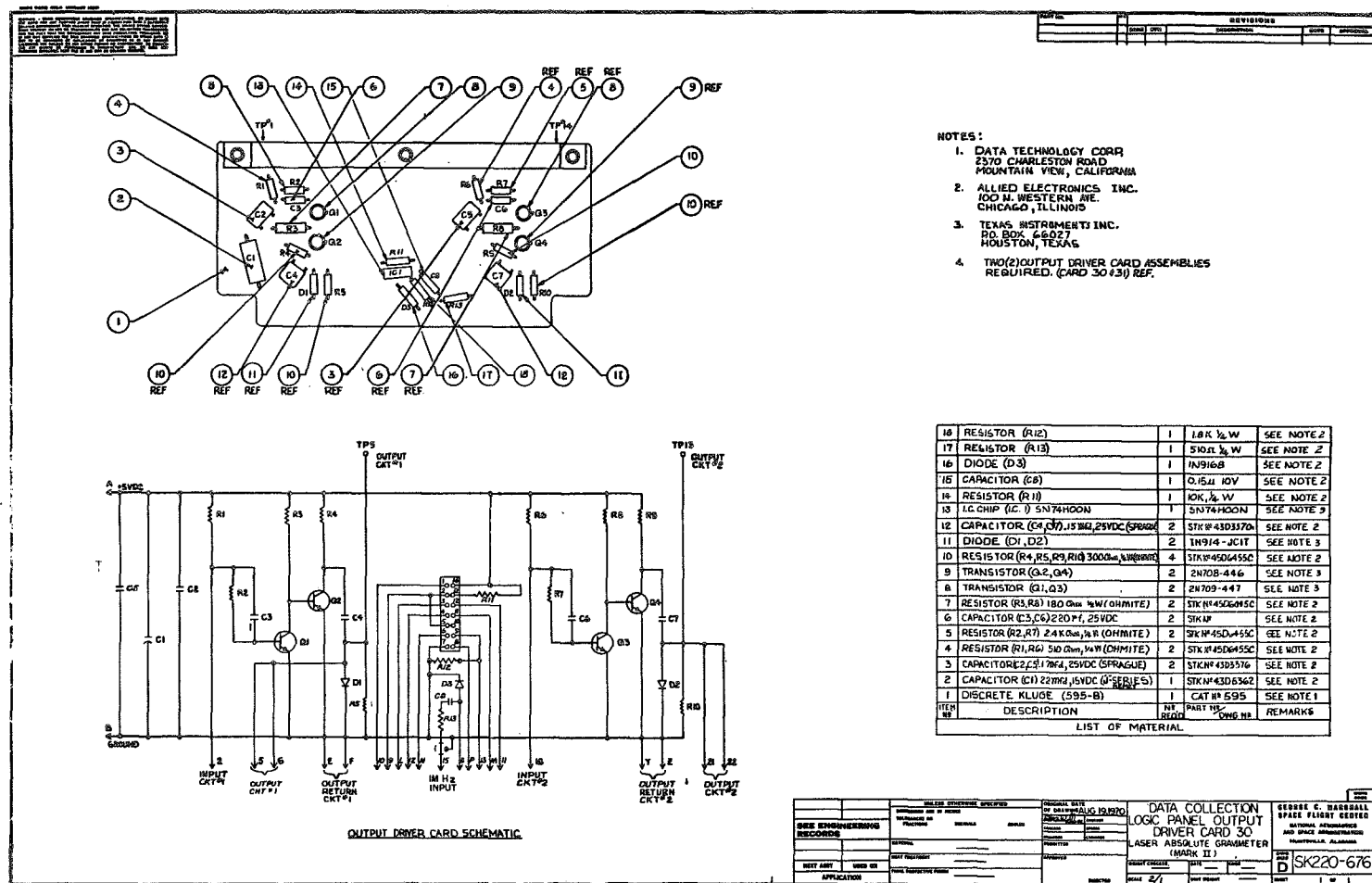


Figure A-13. Data collection logic panel output driver-card 30 – Laser Absolute Gravimeter (Mark II).

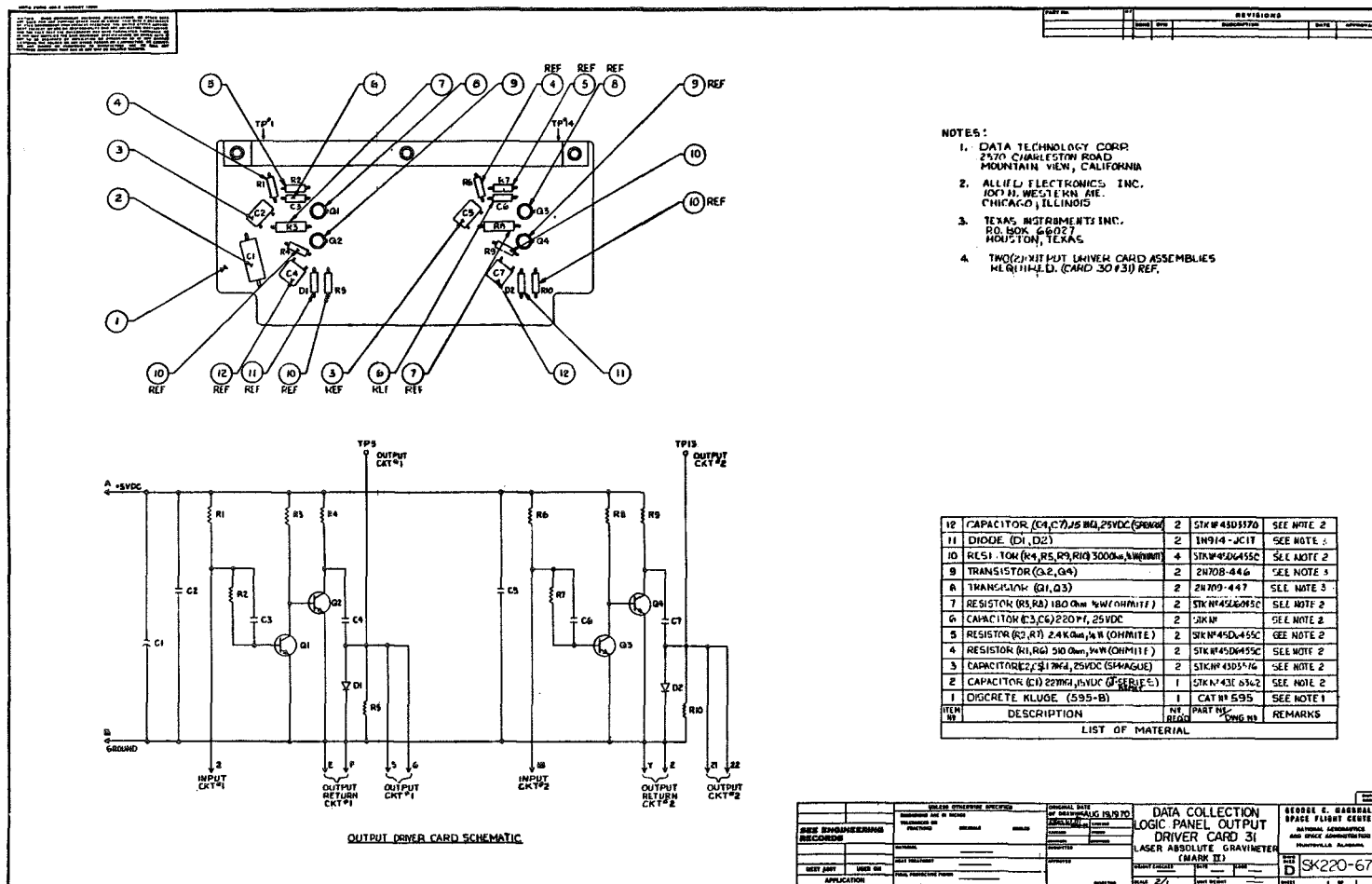


Figure A-14. Data collection logic panel output driver-card 31 – Laser Absolute Gravimeter (Mark II).

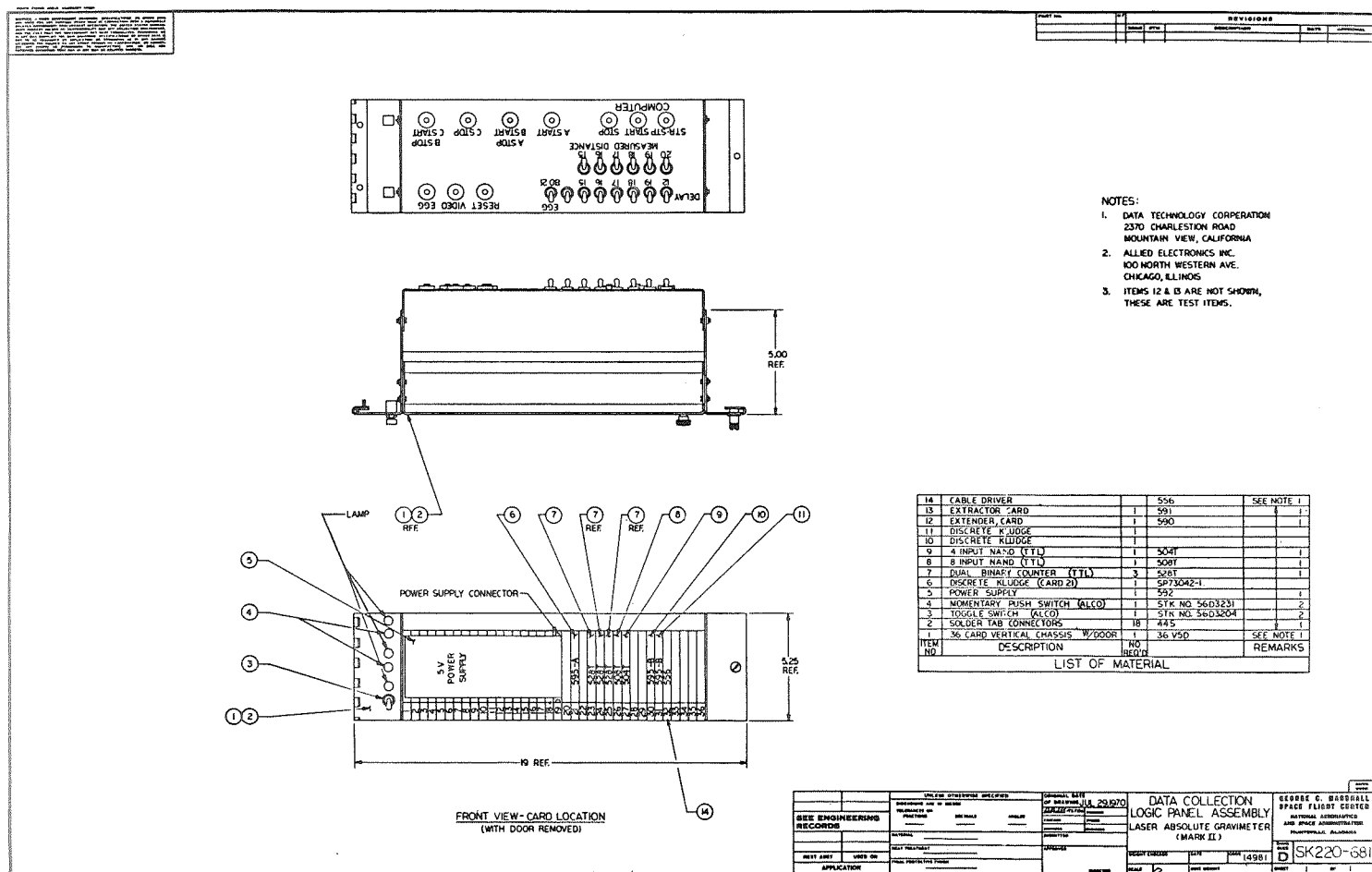
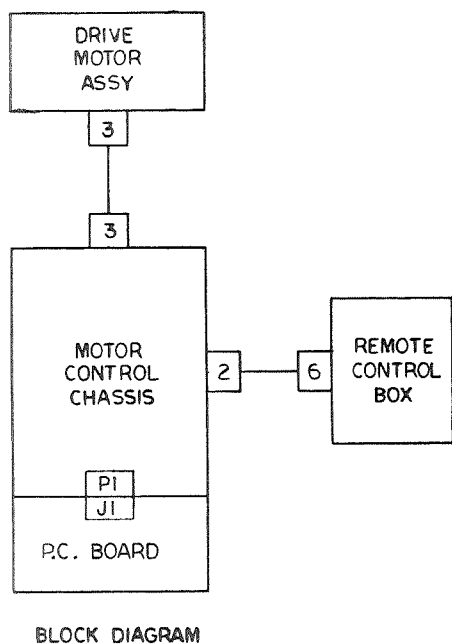


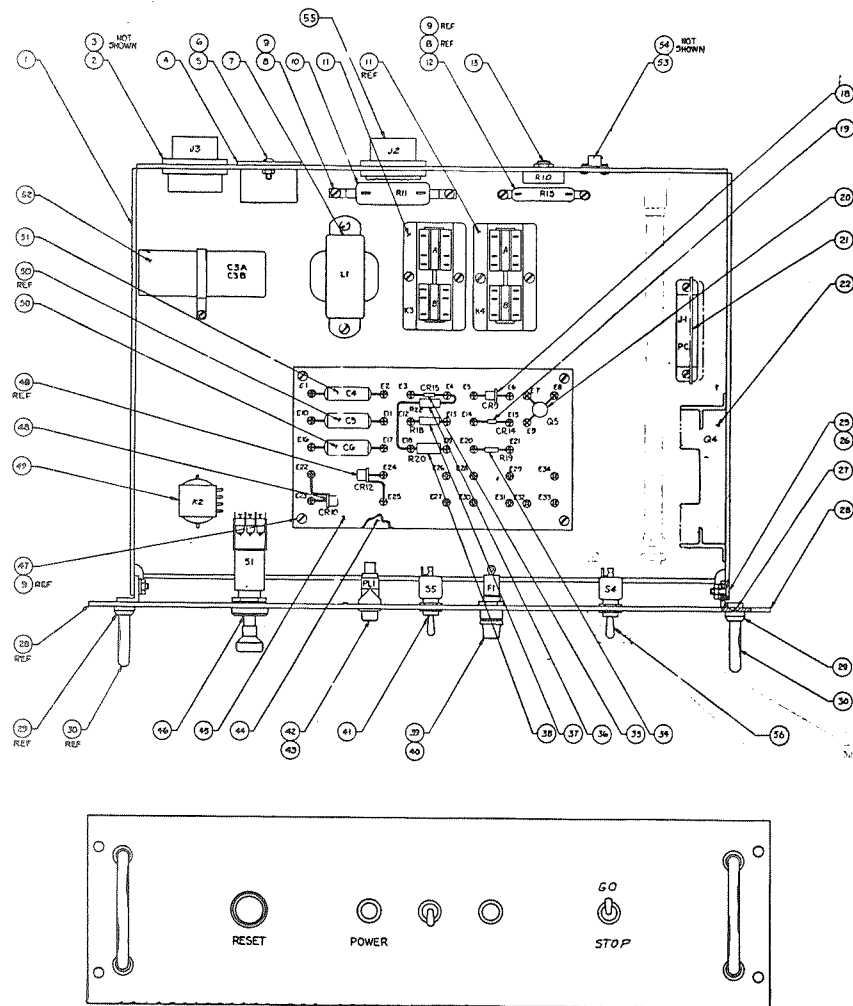
Figure A-15. Data collection logic panel assembly – Laser Absolute Gravimeter (Mark II).



REF NO.	DESCRIPTION	RATING	ECC NO./PART NO.	SUPPLIER
C1, C2	CAPACITOR	.01MFD, 200V (MYLAR)	C2226-7	ECC
C3A		50UF, 200V	C2102	
C3B		250 UF, 200V	C2102	
C4		.015 MFD, 600V	C2204	
C5, C6		.047 MFD, 400V	C2168	
C7	CAPACITOR	.01MFD, 200V (MYLAR)	C2226-7	
CR1-CR6	DIODE	1A, 400V	C2060-4	
CR7		1W, 110V, 5%	C2111-2	
CR8		1A, 50V	C2060-1	
CR9		1A, 400V	C2060-4	
CR10-CR12		3A, 200V	C2169-3	
CR13		1A, 50V	C2060-1	ECC
CR14			IN485B	ALLIED
CR15	DIODE	20V, 5%	IN968B	ALLIED
F1	FUSE	3AG, 125V	C2179-5SB	ECC
L1	CHOKE	100 MH, 1A	C2209	
PL1	PILOT LIGHT	AMP 1-380563-2	C2184	
Q1	TRANSISTOR	2N3710, 2N3565	C2158	
Q2		2N3440	C2159	
Q3		2N3583, 2N3738	C2075	
Q4		(POWER) DELCO DTS 411	C2221	ECC
Q5	TRANSISTOR		2N398B	ALLIED
S1	SWITCH	SPST	C2172	ECC
S2, S3	SWITCH	SUBMINIATURE	ISM1-T	MICRO-SWITCH
R1	RESISTOR	3.9K, 2W, 5% C	C2290-3952	ECC
R2	RESISTOR	39K, 1/2W, 10% C	C2290-3951	
R3	JUMPER		C2163	
R4, R5	RESISTOR	10K, 1/2W, 10% C	C2250-1031	
R6	RESISTOR	150K, 1/2W, 10% C	C2250-1541	
R7	RESISTOR	4.7K, 1/2W, 10% C	C2250-4721	
R8, R9	RESISTOR	22K, 1/2W, 10% C	C2250-2231	ECC
R10	POTENTIOMETER	CARBON CONTROLLER	CLU 253(282533)	ALLIED
R11	RESISTOR	1K, 25W, WW	C2121-5	ECC
R15		2 OHM, 10W, WW	C2115-2	ECC
R18		1.5K, 5%, 1W	GBT-1	IRC
R19		5.6K, 1/2W, 5%	GBT-1/2	
R20	RESISTOR	10K, 2W, 10%	SR-2	
R21	POTENTIOMETER	100K, 20TURN (LINEAR)	I220	
R22	RESISTOR	10 MEG OHMS, 1W	GBT-1	IRC
K2	RELAY		KAI4AG	POTTER BRUMFIELD
K3, K4	LATCHING RELAY		KBI7D	POTTER BRUMFIELD

Figure A-16. Motor control – Laser Absolute Gravimeter (Mark II).

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NOTES:

- ITT CANNON ELECTRIC CO.
1308 HUMBOLDT STREET
LOS ANGELES, CALIFORNIA
- HUBBEL, INC.
KORAYBAR ELECTRIC CO.
2811 UNIVERSITY DR.
HUNTSVILLE, ALABAMA
- THESE COMPONENTS ARE ALL FROM
M-600 SERIES INWIRE CONTROL SYSTEM
ELECTRO CRAFT CORP.
1400 SECOND STREET SOUTH
HOPKINS, MINNESOTA
- POTTER & BRUMFIELD, INC.
RMS ELECTRONICS
P.O. BOX 2308
BIRMINGHAM, ALABAMA
- ALLIED ELECTRONICS CO.
100 NORTH WESTERN AVE.
CHICAGO, ILLINOIS
- PARKER-HANAFIN CO.
TUBE FITTINGS DIV.
17375 FUELID AVE.
CLEVELAND, OHIO
- CAJON COMPANY
32550 OLD SOUTH MILES RD.
CLEVELAND, OHIO
- STERLING INSTRUMENT CO.
76 EAST 2ND STREET
MINEOLA, NEW YORK
- MODERNA VALVE CO.
FLUID POWER OF MEMPHIS
P.O. BOX 14566
MEMPHIS, TENNESSEE
- CUTLER-HAMMER, INC.
ELECTRO AIR CORP.
645 ANTONIE N.W.
ATLANTA, GEORGIA
- ELECTRO AIR CORP.
645 ANTONIE N.W.
ATLANTA, GEORGIA

56	TOGGLE SWITCH	1		
57	8 PIN RECEPTACLE	1		
58	CONNECTOR (CANNON) J6	1	ENC-PL3	SEE NOTE 11
59	JAM NUT RECEPTACLE (CANNON)	1	UC-230A/U	SEE NOTE 11
60	CAPACITOR (C3A) C3B 500V 4500UF 100V	1	C2102	SEE NOTE 3
61	CAPACITOR (C4) (0.15UF, 600V)	1	C2104	SEE NOTE 3
62	CAPACITOR (C5) (0.15UF, 400V)	2	C2105	SEE NOTE 3
63	RELAY (K2)	1	KAM-42	SEE NOTE 3
64	DIODE (CR1) (CR2) (3A, 200V)	2	C2109-3	SEE NOTE 3
65	SCREW, 3-40UNC, SL, PANHD, #5 LG	4		STL CAD R
66	SWITCH (S1) SPST	1	C2172	SEE NOTE 3
67	TERMINAL BOARD ASSY	1	SP73043-5	
68	TERMINAL BOARD SPACER	1	SP73043-4	
69	LAMP (PL1)	1	C2184	SEE NOTE 3
70	PILOT LIGHT ASSEMBLY	1	MP-1803-2	SEE NOTE 3
71	TOGGLE SWITCH (S2) SPST	1	7580-KG	SEE NOTE 3
72	FUSE (F1), 1.5A, 500 BLD	1	C2179-55B	SEE NOTE 3
73	FUSE HOLDER	1	C2109	SEE NOTE 3
74	RESISTOR (R20) (10K, 1/2W, 5%) IRC	1	SR-2	SEE NOTE 3
75	RESISTOR (R18) (1.5K, 1/2W, 5%) IRC	1	GBY-1	SEE NOTE 3
76	RESISTOR (R22) (100K, 1/2W, 5%) IRC	1	GBY-1	SEE NOTE 3
77	DIODE (CR3) (20V, 1A) IRC	1	IN768B	SEE NOTE 3
78	RESISTOR (R19) (56K, 1/2W, 5%) IRC	1	GBY-1	SEE NOTE 3
79				
80	CHASSIS HANDLES	2	504-1-4	SEE NOTE 3
81	FERRULES	4	504-4-1	SEE NOTE 3
82	ELECTRICAL PANEL	1	SP73043-3	
83	SCREW, 10-32UNC, FL HD 100" #5 LG	4		STL CAD R
84	NUT, 8-32UNC, HEX, PLAIN	6		STL CAD R
85	SCREW, 8-32UNC, FL HD 100" #5 LG	6		STL CAD R
86				
87	TRANSISTOR M557 (HEAT SINK) (Q1)	1	1608P6	SEE NOTE 3
88	PRINTED CIRCUIT BOARD ASSEMBLY (PCB)	1	7608P6	SEE NOTE 3
89	TRANSISTOR (Q2)	1	2N3758B	SEE NOTE 3
90	DIODE (CR4)	1	IN4850	SEE NOTE 3
91	DIODE (CR9) (10A, 400V)	1	C2060-4	SEE NOTE 3
92				
93	CARBON CONTROLLER ROT. OIL LOCK (S1)	1	504-1-4	SEE NOTE 3
94	RESISTOR (R15) (1/2W, 200K, 5%) IRC	1	C2110-2	SEE NOTE 3
95	RELAY (K3) (40A)	2	KB17D	SEE NOTE 3
96	RESISTOR (R11) (1/2W, 10K, 5%) IRC	1	C2111-5	SEE NOTE 3
97	NUT, 3-40UNC, HEX, PLAIN	19		STL CAD R
98	SCREW, 3-40UNC, PAN HD, SLOTTED #4 LG	15		STL CAD R
99	CHOKE (L1) 100UH, JA	1	C2209	SEE NOTE 3
100	NUT, 1/2-20UNC, HEX, PLAIN	2		STL CAD R
101	SCREW, 1/2-20UNC, PAN HD, SLOTTED #5 LG	2		STL CAD R
102	RECEPTACLE (M1) (1/2" FLANGED INLET)	1	7608P6	SEE NOTE 3
103	CONNECTOR PLUG	1	K708402-6	SEE NOTE 3
104	JAM NUT RECEPTACLE	1	K708402-6	SEE NOTE 3
105	ELECTRICAL RACK	1	SP73043-1	SEE NOTE 3
106				
107	DESCRIPTION	BY	DATE	REMARKS

LIST OF MATERIAL

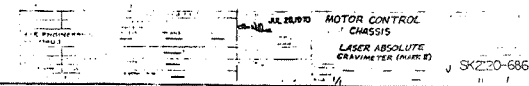


Figure A-18. Motor control chassis – Laser Absolute Gravimeter (Mark II).

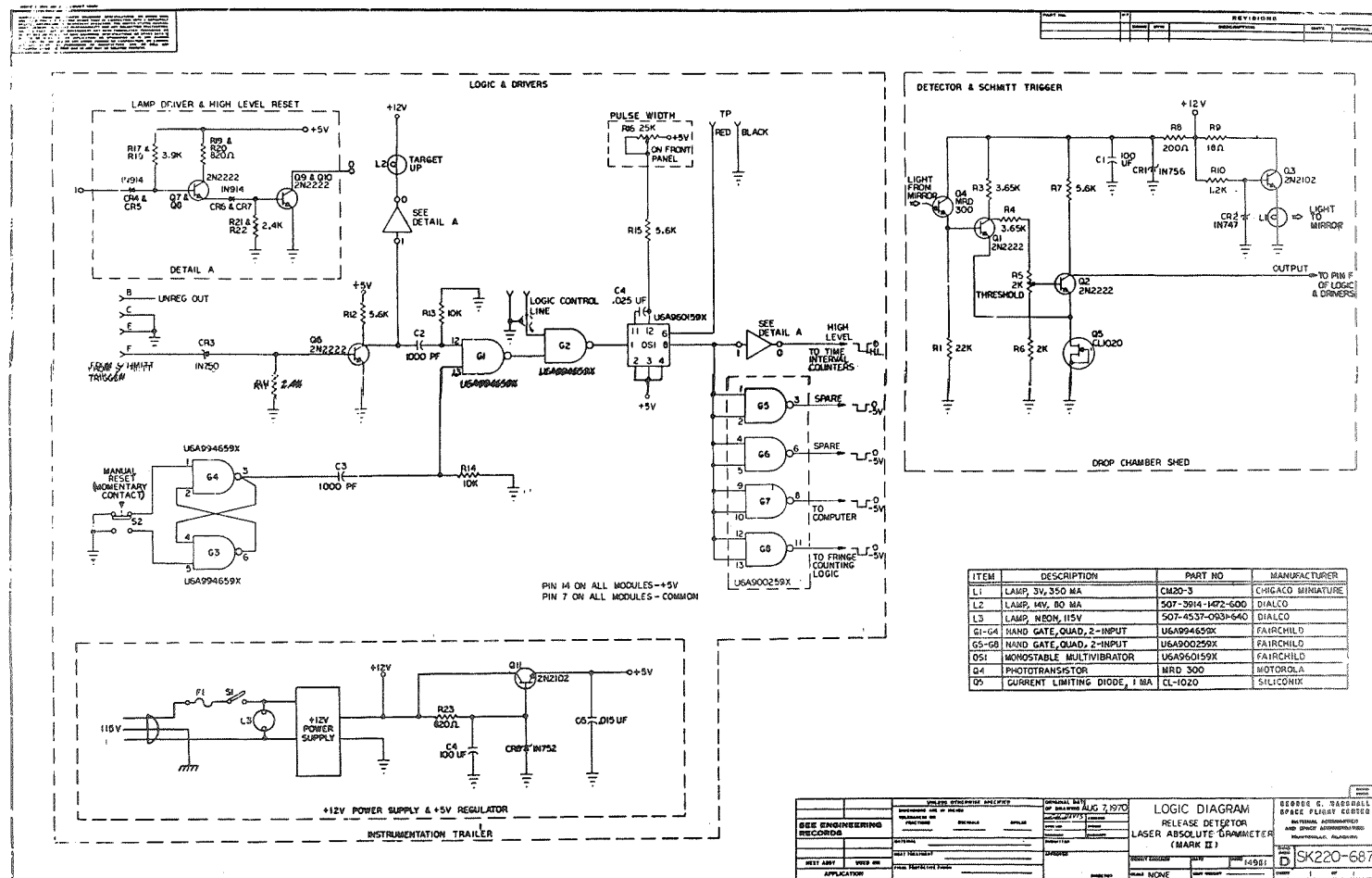


Figure A-19. Logic diagram release detector – Laser Absolute Gravimeter (Mark II).

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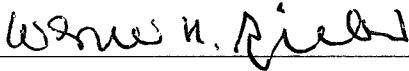
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OPERATION MANUAL FOR THE MARK II MODEL
OF THE LASER ABSOLUTE GRAVIMETER

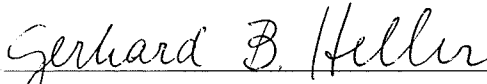
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